VAN NOSTRAND'S

ECLECTIC

ENGINEERING MAGAZINE.

NO. CX.—FEBRUARY, 1878.—VOL. XVIII.

A NEW GENERAL METHOD IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

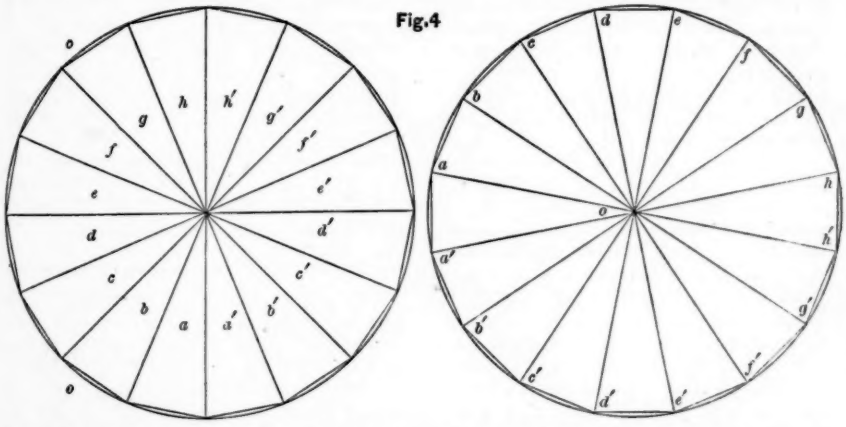
Written for VAN NOSTRAND'S MAGAZINE.

II.

WHEEL WITH TENSION-ROD SPOKES.

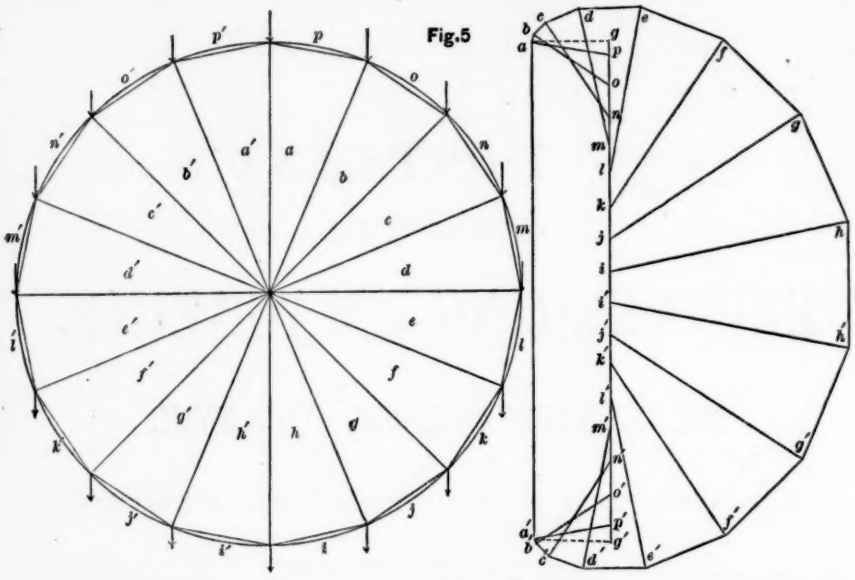
A very interesting example is found in the wheel represented in Fig. 4, in which the spokes are tension rods, and the rim is under compression. Let the greatest weight which the wheel ever sustains be applied at the hub of the wheel on the left, and let this weight be represented by the force aa' on the right, which is also equal to the reaction of the point of support upon which the wheel stands; hence aa' represents the force acting between two joints of this frame. The same effect would be caused

Fig. 4



upon the other members of the frame by "keying" the rod aa' sufficiently to cause this force to act between the hub and the lowest joint.

It should be noticed in passing, that the weights of the parts of the wheel itself are not here considered; their effect will be considered in Fig. 5. Also, the



construction is based upon the supposition that there is a flexible joint at the extremity of each spoke. This is not an incorrect supposition when the flexibility of the rim is considerable compared with the extensibility of the spokes, a condition which is fulfilled in practice.

A similar statement holds in the case of the roof truss with continuous rafters, or a bridge truss with a continuous upper chord. The flexibility of the rafters or the upper chord is sufficiently great in comparison with the extensibility of the bracing, to render the stresses practically the same as if pin joints existed at the extremities of the braces.

Furthermore, the extremities of the spokes are supposed to be joined by straight pieces, since the forces between the joints of the rim act in those directions. Such forces will cause small bending moments in the arcs of the rim joining the extremities of the spokes. Each arc of the rim is an arch subjected to a force along its chord or span, and it can be treated by the method applicable to arches. This discussion is unimportant in the present case and will be omitted.

Upon completing the force polygon in the manner previously described, it is found that the stress on every spoke is the same in amount, and is represented by a side of the regular polygon *abcd*, etc. upon the left, while the compression of the pieces of the rim are represented by the radii *oa ob*, etc.

As previously explained these diagrams are mutually reciprocal, and it happens in this case that they are also similar figures.

We then conclude that in designing such a wheel each spoke ought to be proportioned to sustain the total load, and that the maker should key the spokes until each spoke sustains a stress at least equal to that load. Then in no position of the wheel can any spoke become loose. The load here spoken of, includes, of course, the effect of the most severe blow to which the wheel may be subjected while in motion.

WATER WHEEL WITH TENSION-ROD SPOKES.

The effect of a load distributed uniformly around the circumference of such a wheel as that just treated is represented in Fig. 5. Should it be desirable to compute the effect of both sets of forces upon the same wheel, it will be sufficient to take the sum of the separate effects upon each piece for the total effect upon that piece, though it is perfectly possible to construct both at once.

GENERAL LIBRARY University of MICHIGAN

We shall suppose a uniform distribution of the loading along the circumference in the case of the Water Wheel, because in wheels of this kind such is practically the case so far as the spokes are concerned, since the power is transmitted, not through them to the axis, but, instead, to a cog wheel situated near the center of gravity of the "water arc." This arrangement so diminishes the necessary weight of the wheel, and the consequent friction of the gudgeons, as to render its adoption very desirable.

The discussion of the stresses appears however, to have been heretofore erroneously made.*

Let the weight pp', at the highest joint of the wheel, be sustained by the rim alone, since the spoke aa' cannot assist in sustaining pp', as aa' is suited to resist tension only. Conceive, for the moment, that two equal and opposite horizontal forces are introduced at the highest joint such as the two parts of the rim exert against each other, then $\frac{1}{2}pp'=pq=p'q'$ being sustained by each of the pieces ap, $a'p'$ respectively we have apq and $a'p'q'$ as the triangles which together represent the forces at the highest joint. The force aa' on the right is the upward force at the axis, equal and opposed to the resultant of the total load upon the wheel, and the apparent peculiarity of the diagram is due to this;—the direction of the reaction or sustaining force of the axis passes through the highest joint of the wheel and yet it is not a force acting between those joints and could not be replaced by keying the tie connecting those joints. In other particulars the force diagram is constructed as previously described and is sufficiently explained by the lettering. Should the spoke aa' have an initial tension greater than pp', then there is a residual tension due to the difference of those quantities whose effect must be found as in Fig. 4.

Should the wheel revolve with so great a velocity that the centrifugal force must be considered, its effect will be to increase the tension on each of the spokes by the same amount,—the amount due to the deviating force of the mass supposed to be concentrated at the extremity of each spoke. The compression of the rim may be decreased by the centrifugal force, but as this is a temporary relief, occurring only during the motion, it does not diminish the maximum compression to which the rim will be subjected.

We conclude then, that every spoke must be proportioned to endure a tension as great as hh' from the loading alone; and that if other forces, due to centrifugal force or to keying, are to act they must be provided for in addition. Furthermore, we see that the rim must be proportioned to bear a compression as great as hi, due to the loading alone, and that the centrifugal force will not increase this, but any keying of the spokes beyond that sufficient to produce an initial tension on each spoke as great as pp' must be provided for in addition.

The diagram could have been constructed with the same facility in case the applied weights had been supposed unequal.

It can be readily shown that the differential equation of the curve circumscribing the polygon $abcd$, etc. of Fig. 5 is

$$y+x\frac{dx}{dy}+c\tan.^{-1}\left(\frac{dx}{dy}\right)=0$$

which equation is not readily integrable. When, however, the number of spokes is indefinitely increased, it appears from simple geometrical considerations that this curve becomes a cycloid having its cusps at q and q'.

ASSUMED FRAMING.

Thus far, we have treated the effect of known external forces upon a given form of framing, and it is evident from the previous discussions and the illustrative examples that any such problem, which is of a determinate nature, can be readily solved by this method. But in case the problem under discussion has reference to the relations of forces among themselves, it is necessary to assume that the forces are applied to a frame or other body, in order to obtain the required relationship. Certain general forms of assumed framing have properties which are of material assistance in treating such problems, and this is true to such an extent that even though the form of framing to which the forces are applied is given, it is still advantageous to assume, for the time being, one of the

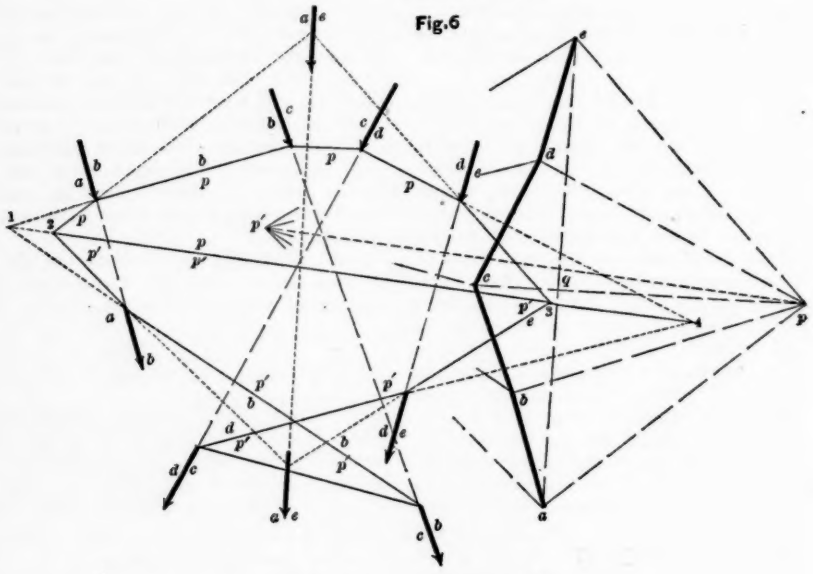
* "A Manual of the Steam Engine, etc.," by W. J. M. Rankine. Page 182, 7th Ed.

forms having properties not found in ordinary framing. The special framing which has been heretofore assumed for such purposes is the Equilibrium Polygon, whose various properties will be treated in order. We now propose another form of framing, which we have ventured to call the Frame Pencil, with equally advantageous properties which will also be treated in due order.

It may be mentioned here, that the particular case of parallel forces is that most frequently met with in practice. In case of parallel forces the properties of the equilibrium polygon and frame pencil are more numerous and important than those belonging to the general case alone. We shall first treat the general case, and afterwards derive the additional properties belonging to parallel forces.

EQUILIBRIUM POLYGON.

Fig. 6



RECIPROCAL FIGURES.

Direction and Position.	*Force Diagram,*	*abcde,*	*Force Polygon.*	*Direction and Magnitude.*
	Equilibrium Polygon,	*ap, bp, cp, dp, ep,*	*Force Pencil.*	
	Equilibrium Polygon,	*ap', bp', cp', dp', ep',*	*Force Pencil.*	
	Closing Line,	23 ∥ *pq,*	*Closing Ray.*	
	Resultant Force,	*ae,*	*Resultant Force.*	

THE EQUILIBRIUM POLYGON FOR ANY FORCES IN ONE PLANE.

Let *ab, bc, cd, de* Fig. 6 be the diagram of any forces lying in the plane of the paper, and *abcde* their force polygon, then, as previously shown, *ae* the closing side of the polygon of the applied forces represents the resultant of the given forces in amount and direction. Assume any point *p* as a pole, and draw the force pencil *p—abcde*. The object in view in so doing, is to use this force pencil and polygon of the applied forces together in order to determine a figure of which it is the reciprocal.

From any convenient point as 2 draw the side *ap* parallel to the ray *ap* until it intersects the line of action of the force *ab*, and from that intersection draw the side *bp* parallel to the ray *bp*, etc., etc.; then the polygon *p* will have its sides parallel respectively to the rays of the pencil *p*.

The polygon *p* and the given forces *ab, bc*, etc, then form a force and frame diagram to which the pencil *p—abcde* is

reciprocal, and of which it is the force diagram. It is seen that no internal bracing is needed in the polygon p, and hence it is called an equilibrium (frame) polygon: it is the form which a funicular polygon, catenary, or equilibrated arch, would assume if occupying this position and acted upon by the given forces.

As represented in Fig. 6 the sides of the polygon p are all in compression so that p represents an ideal arch. If the line 23 be drawn cutting the sides ap, ep so that it be considered to be the span of the arch having the points of support 2 and 3, then this arch exerts a thrust in the direction 23 which may be borne either by a tie 23 or by fixed abutments 2 and 3: the force in either case is the same and is represented by $pq \parallel 23$. It is usual to call 23 a closing line of the polygon p. The point q divides the resultant ae into two parts such that $qapq$ and $epqe$ are triangles whose sides represent forces in equilibrium, *i.e.*, the forces at the points 2 and 3; hence, qa and eq are the parts of the total resultant which would be applied at 2 and 3 respectively.

This method is frequently employed to find the forces acting at the abutments of a bridge or roof truss such as that in Fig. 2. But it appears that it has often been erroneously employed. It must be first ascertained whether the reaction at the abutments is really in the direction ae for the forces considered. It may often happen far otherwise. If the surfaces upon which the truss rests without friction are perpendicular to ae, then this assumption is probably correct; as, for instance, when one end is mounted on rollers devoid of friction, running on a plate perpendicular to ae. But in cases of wind pressure against a roof truss the assumption is believed to be in ordinary cases quite incorrect. Indeed, the friction of the rollers at end of a bridge has been thought to cause a material deviation from the determination founded on this assumption. It is to be noticed that any point whatever on pq (or pq prolonged) might be joined to a and e for the purpose of finding the reactions of the abutments. Call such a point x (not drawn), then ax and ex might be taken as two forces which are exerted at two and 3 by the given system. It appears necessary to call attention to this point, as the fallacious determination of the reactions is involved in a recently published article upon this subject.* We shall return to the subject again while treating parallel forces and shall extend the method given in connection with Fig. 2 to certain definite assumptions, such as will determine the maximum stresses which the forces can produce.

Prolong the two sides ap and ep of the polygon p until they meet. It is evident that if a force equal to the resultant ae be applied at this intersection of ap and ep prolonged, then the triangles apq and epq will represent the stresses produced at 2 and 3 by the resultant. But as these are the stresses actually produced by the forces, and as the resultant should cause the same effects at 2 and 3 as the forces, it follows that the intersection of ap and ep must be a point of the resultant ae; and if, through this intersection, a line be drawn parallel to the resultant ae, it will be a diagram of the resultant, showing it in its true position and direction.

This is in reality a geometric relationship and can be proved from geometric considerations alone. It is sufficient for our purposes, however, to have established its truth from the above mentioned static considerations which may be regarded as mechanical proof of the geometric proposition.

The pole p was taken at random: let any other point p' be taken as a pole. To avoid multiplying lines p' has been taken upon pq. Now draw the force pencil $p'—abcde$ and the corresponding equilibrium polygon for the same forces ab, bc, etc. This equilibrium polygon has all its pieces in tension except $p'c$. It is to be noticed that the forces are employed in the same order as in the previous construction, because that is the order in the polygon of the applied forces: but the order of the forces in the polygon of the applied forces is, at the commencement, a matter of indifference, for the construction did not depend upon any particular succession of the forces.

As previously shown, the intersection of ap' with ep' is a point of the resultant, and the line joining this intersection

* See paper No. 71 of the Civil Engineers' Club of the Northwest. Applications of the Equilibrium Polygon to determine the Reactions at the Supports of Roof Trusses. By James R. Willett, Architect. Chicago.

with the corresponding intersection above is parallel to *ae*.

Again, prolong the corresponding sides of the two equilibrium polygons until they intersect at 1234, these points fall upon one line parallel to *pp'*. For, suppose the forces which are applied to the lower polygon *p'* to be reversed in direction, then the system applied to the polygons *p* and *p'* must together be in equilibrium; and the only bracing needed is a piece 23 ‖ *pp'*, since the upper forces produce a tension *pq* along it, and the lower forces a tension *qp'*, while the parts *aq* and *qe* of the resultant which are applied at 2 and 3 are in equilibrium. The same result can be shown to hold for each of the forces separately; *e.g.* the opposite forces *ab* may be considered as if applied at opposite joints of a quadrilateral whose remaining joints are 1 and 2 : the force polygon corresponding to this quadrilateral is *apbp'*, hence 12 ‖ *pp'*. Hence 1234 is a straight line. The intersection of *pc* and *p'c* does not fall within the limits of the figure.

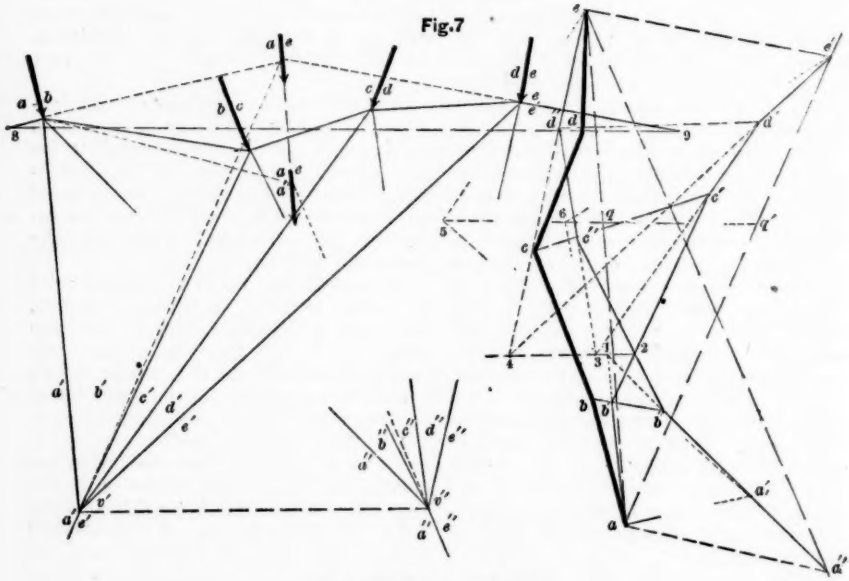
It is to be noticed that the proposition just proved respecting the collinearity of the intersections of the corresponding sides of these equilibrium polygons is one of a geometric nature and is susceptible of a purely geometric proof.

THE FRAME PENCIL FOR ANY FORCES IN ONE PLANE.

Let *ab*, *bc*, *cd*, *de* in Fig. 7 represent a system of forces, of which *abcde* is the force polygon. Choose any single point upon the line of action of each of these

FRAME PENCILS.

Fig.7



RECIPROCAL FIGURES.

Direction and Position.	*Force Diagram*,	*a b c d e*,	*Force Polygon.* — *Direction and Magnitude.*
	Frame Pencil,	*a' b' c' d' e'*,	*Equilibrating Polygon.*
	Frame Pencil,	*a'' b'' c'' d'' e''*,	*Equilibrating Polygon.*
	Frame Polygon,	*bb', cc', dd', ee'*,	*Force Lines.*
	Resultant Force,	*a e*,	*Resultant Force.*
	Resultant Ray,	*a' e'*,	*Resultant Side.*

forces, and join these points to any assumed vertex *v'* by the rays of the frame pencil *a'b'c'd'e'*. Also join the successive points chosen by the lines *bb'*, *cc'*, *dd'* which form sides of what we shall call the frame polygon. Now consider the

given forces to be borne by the frame pencil and frame polygon as a system of bracing, which system exerts a force at the vertex v' in some direction not yet known, and also exerts a force along some assumed piece ee', which may be regarded as forming a part of the frame polygon. The stresses upon the rays of the frame pencil will be represented by the sides of $ab'c'd'e'$ which we shall call the equilibrating (force) polygon; while the stresses in the frame polygon are given by the force lines bb', cc', etc. If a resultant ray $a'e'$ be drawn from v' parallel to the resultant side ae' of the equilibrating polygon it will intersect ee' at a point of the resultant of the system of forces; for that is a point at which if the resultant be applied it will cause the same stresses along the pieces $a'e'$ and ee' which support it as do the forces themselves.

If the point e' in the force polygon be moved along $e'd'$, the locus of the intersection of the corresponding positions of the resultant ray $a'e'$ and the last side ee' will be the resultant ae. It would have been unnecessary to commence the equilibrating polygon at a had the direction of aa' been known. Having obtained the direction of aa' as shown at 8, the equilibrating polygon could be drawn by commencing at any point of $aa_1 \parallel aa'$.

In cases like that in the Fig., where there is no reason for choosing the points which determine the sides of the frame polygon otherwise, it is simpler to make the frame polygon a straight line, which may in that case be called the frame line. Then the force lines are parallel to each other and to aa' also. This is a practical simplification of the general case of much convenience.

It should be noticed here that the equilibrium polygon, as well as the straight line, is one case of the frame polygon. The interesting geometric relationships to be found by constructing the frame and equilibrium polygons as coincident must be here omitted.

Suppose that it is desired to find the point q which divides the resultant into two parts, which would be applied in the direction of the resultant at two such points as 8 and 9: draw $a6 \parallel v'8$ and $e'6 \parallel v'9$ and then through 6 draw $qq' \parallel 89$. This may be regarded as the same geometric proposition, which was proved when it was shown that the locus of the intersection of the two outside lines of the equilibrium polygons (reciprocal to a given force pencil) is the resultant, and is parallel to the closing side of the polygon of the applied forces. The proposition now is, that the locus of the intersection of the two outside lines of the equilibrating polygon (reciprocal to a given frame pencil) is the resolving line, and is parallel to the abutment line: for these two statements are geometrically equivalent.

Assume a different vertex v'', and draw the frame pencil and its corresponding equilibrating polygon $a''b''c''d''e$. If a_1 5 and e 5 be drawn parallel to v'' 8 and v'' 9 respectively their intersection is upon qq' as before proven.

Again, the corresponding sides of these two equilibrating polygons intersect at 1 2 3 4 upon a line parallel to $v'v''$, for this is the same geometric proposition respecting two vertices and their equilibrating polygons which was previously proved respecting two poles and their equilibrium polygons.

It would be interesting to trace the geometric relations involved in different but related frame polygons, as for example, those whose corresponding sides intersect upon the same straight line, but as our present object is to set forth the essentials of the method, a consideration of these matters is omitted. Enough has been proven, however, to show that we have in the frame pencil an independent method equally general and fruitful with that of the equilibrium polygon.

IRON articles to be bronzed are, according to a process by M. P. Hess, heated in the air after being coated with linseed oil. Objects which cannot be exposed to high temperature may be steeped in a slightly acid solution of ferric chloride, plunged in hot water, and when dry rubbed with linseed oil or with wax. To preserve iron from rust the author recommends sulphide of copper. He steeps the iron for a few minutes in a solution of sulphate of copper, and then transfers it into a solution of hyposulphite of soda acidulated with hydrochloric acid. The result is a blue-black coating, not affected by air or water.

THE ANEROID BAROMETER, ITS CONSTRUCTION AND USE.

Compiled for VAN NOSTRAND'S MAGAZINE.

I.

Two forms of Barometer are used by physicists for measuring the pressure of the atmosphere: the Mercurial and the Aneroid. The first was invented by Toricelli in 1643. It is too well known to require description; it will be sufficient to say that it measures the varying pressure of the air by the varying length of a column of mercury which balances the pressure.

The Aneroid was invented about the beginning of this century, but was not brought to a serviceable form until within the last thirty years when M. Vidi of Paris succeeded in conquering the difficulties of construction and produced an instrument which has of late been steadily gaining in the estimation of scientists. Meteorologists, geographical explorers, and civil engineers alike concur in praising the usefulness and accuracy of the more portable forms of this instrument. It is, however, only the best and latest improved construction that will justify such confidence.

Captain R. H. Fawcett, who has had much practice in contouring, writes in the *United Service Journal*, vol. xvi.: "The value of the aneroid as a handy and portable instrument for rapidly obtaining relative heights in surveys, has, I think, been under-rated. It is of great value, especially in cases of military surveying, where time is frequently priceless. The points chiefly valuable in an aneroid are its portability, as in the pocket it takes up no more room than a watch, and the observations and calculations can be done so quickly that a staff officer riding from one hill to another can readily obtain their relative heights. In a survey readings may be noted down in a pocket-book, or even on the margin of the sketch, and calculated out on return at leisure. When there is plenty of time and the ground is practicable, leveling or contouring would certainly be adopted in preference; but even then the occasional consultation of the aneroid might be an advantageous check to error. But if pressed for time, or contouring be impracticable or extremely difficult, the aneroid gives heights with sufficient accuracy for ordinary military operations, and is far more accurate than the eye; moreover, the reading may be taken in equal or less time than it would require in most cases to make a good judgment of height. . . . Though it cannot show the height with the accuracy of leveling or contouring, yet its indications may be generally relied on to ten feet or twenty feet. . . . It is of course in abrupt, hilly and almost mountainous countries that the aneroid is most useful. For heights of fifty feet or sixty feet above the plain varying slightly in their relative heights, the reading of the pocket aneroid might be difficult, and the slightest error important. . . . It almost invariably happens that such small heights can be contoured or leveled quickly, but the case is different with hills of 300 feet or 400 feet above points in the survey. The contouring of these would take up much time, and the advantage of the aneroid, as far as this reason goes, increases with the height."

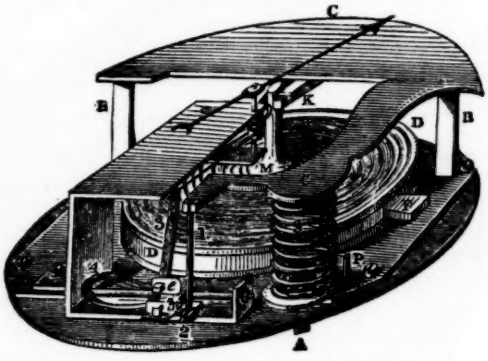
Thus the traveler amid snowy peaks and glaciers, on plateau or prairie, can tell within a hundred feet his elevation above the sea; a triumph of science no less wonderful than that by which he ascertains his latitude by means of the sextant. With due precautions the aneroid will measure heights with surprising accuracy, as has been repeatedly proved

by trigonometrical measurements. For rough practical purposes it is all that can be desired for contouring mountains and hilly districts, with rapidity. It is unnecessary to dwell upon the value of these results to the sciences of geography and topography. Sir J. Herschel in his treatise on "Physical Geography" remarks on this subject: "Barometrical observations both stationary and itinerant, assisted of late by that very useful and portable form of the barometer called the aneroid, which can be read off in a carriage or on horseback, have been now so far extended over the whole accessible surface of the globe, as to afford ground for a reasonable conclusion respecting the average elevation of the surface of the land above the sea level, and a very accurate one as to the heights of mountain chains and summits.

The aneroid depends for its action upon the changes in form of a thin metallic box partially exhausted of air, as the pressure of the atmosphere varies. In Vidi aneroid the metallic box was cylindrical in shape with thin corrugated ends. In some later forms the box is crescent or ⊃ shaped.

The following diagrams exhibit the mechanism of the instrument:

The vacuum chamber, A (Fig. 1) is



flat and circular, having its top and bottom corrugated in concentric circles, to render them more elastic. In the best constructed aneroids the top of the chamber is, in a certain degree, held up in opposition to the pressure of the atmosphere by the elasticity of a folded lamina of spring steel, B, the pull of which on the chamber is regulated by the pressure of a screw beneath the arm, C; by means of this screw, which is reached from an aperture in the bottom of the case, the index error may be corrected whenever such is found to exist; and it may be here remarked that small index errors will occasionally arise, until by a little time and use, the numerous moveable parts of the instrument have assumed their permanent bearings; when, however, it is duly seasoned, it may, if originally well constructed, be carried about with ordinary care in traveling, without undergoing any sensible change. change.

The folded spring, B, is firmly connected with a stud on the center of the vacuum chamber (which has been carefully exhausted by an air-pump, and the aperture soldered up), and rises and falls with it in obedience to atmospheric pressure. An arm, D, is attached to the spring, at the further extremity of which the actual movements of B are considerably amplified.

The end of D is connected by a link with a short arm proceeding from a transverse bar, F, which is movable on its axis. A long arm proceeding upwards from F, is attached by its extremity, G, to the end of a steel chain (similar to the fusee chain of an English watch), which is wound round a small pulley on the axis of the hand or index. A spiral balance-spring, attached by one end to the pulley, and by the other to the framework, opposes the pull on the chain at G, and causes the index to retreat when the chain is relaxed.

Fig. 2 exhibits in perspective a form slightly different; the spiral-spring S

performing the same function as the laminated spring B in Fig 1.

The errors to which the aneroid is subject arise from the property of the metals used in construction to vary their dimensions with every change of temperature, and thus introduce motions into the mechanism which are independent of atmospheric pressure.

The mercurial barometer is subject to fluctuations due to temperature, but these are easily allowed for as the possible changes are few and simple; but in the aneroid, where metals whose elasticity is not constant are under tension, it is readily comprehended that skillful adjustment is needed to secure *compensation* as it is termed. This is partly effected by the residue of air in the sealed box, but a further adjustment of a compound spring is also required. The aneroid requires occasional comparison with a standard mercurial barometer and a correction when it varies, to make it agree.

When the barometer is employed for the purposes of meteorology only, the following facts are taken into consideration. We quote from Buchan's "Handy Book of Meteorology":

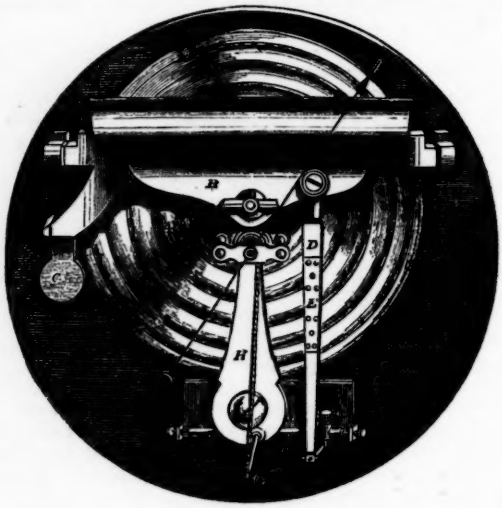


FIG. 2.

Variations of the Barometer.—The variations observed in the pressure of the air may be divided into two classes—viz., periodical and irregular; the periodical variations recurring at regular intervals, whilst the irregular variations observe no stated times. The most marked of the periodical variations is the *daily variation*, the regularity of which in the tropics is so great that, according to Humboldt, the hour may be ascertained from the height of the barometer without an error of more than 15 or 17 minutes on the average. This horary oscillation of the barometer is masked in Great Britain by the frequent fluctuations to which the atmosphere is subjected in these regions. It is, however, detected by taking the mean of a series of hourly observations conducted for some time. The results show two maxima occurring from 9 to 11 A.M. and from 9 to 11 P.M., and two minima occurring from 3 to 5 A.M. and from 3 to 5 P.M. (*See Table on following page.*)

The maxima occur when the temperature is about the mean of the day, and the minima when it is at the highest and lowest respectively.

This daily fluctuation of the barometer is caused by the changes which take place from hour to hour of the day in the temperature, and by the varying quantity of vapor in the atmosphere.

The surface of the globe is always divided into a day and night hemisphere, separated by a great circle which revolves with the sun from east to west in twenty-

TABLE SHOWING THE DAILY VARIATIONS AND RANGE OF THE BAROMETER IN DIFFERENT LATITUDES.

	LAT.	A.M.		P.M.		RANGE.
		MIN.	MAX.	MIN.	MAX.	
		Inches.	Inches.	Inches.	Inches	Inches.
Atlantic Ocean.....	0 0	—.056	+.069	—.045	+.045	.125
Pacific Ocean.....	0.0	—.032	+.040	—.045	+ 028	.085
Sierra Leone.....	8.28 N.	—.022	+.032	—.038	+.031	.070
Lima.....	12.3 S.	— 071	+.065	—.067	+.050	.136
Calcutta.....	22.36 N.	—.017	+.052	—.038	+.018	.090
Pekin.....	39.53 N.	—.038	+ 047	—.052	+.014	.099
Great St. Bernard.....	45.51 N.	—.010	+.005	—.003	+.012	.022
Plymouth (England)...	50.21 N.	—.007	+.006	—.010	+.010	.020
St. Petersburg.....	59.58 N.	—.003	+.008	—.004	+.002	.012

four hours. These two hemispheres are thus in direct contrast to each other in respect of heat and evaporation. The hemisphere exposed to the sun is warm, and that turned in the other direction is cold. Owing to the short time in which each revolution takes place, the time of greatest heat is not at noon, when the sun is in the meridian, but about two or three hours thereafter; similarly, the period of greatest cold occurs about four in the morning. As the hemisphere under the sun's rays becomes heated, the air, expanding upwards and outwards, flows over upon the other hemisphere where the air is colder and denser. There thus revolves round the globe from day to day a wave of heat, from the crest of which air constantly tends to flow towards the meridian of greatest cold on the opposite side of the globe.

The barometer is influenced to a large extent by the elastic force of the vapor of water invisibly suspended in the atmosphere, in the same way as it is influenced by the dry air (oxygen and hydrogen). But the vapor of water also exerts a pressure on the barometer in another way. Vapor tends to diffuse itself equally through the air; but as the particles of air offer an obstruction to the watery particles, about 9 or 10 A.M., when evaporation is most rapid, the vapor is accumulated or pent up in the lower stratum of the atmosphere, and being impeded in its ascent its elastic force is increased by the reaction, and the barometer consequently rises. When the air falls below the temperature of the dew-point, part of its moisture is deposited in dew, and since some time must elapse before the vapor of the upper strata can diffuse itself downwards to supply the deficiency, the barometer falls—most markedly at 10 P.M., when the deposition of dew is greatest.

Hence, as regards temperature, the barometer is subject to a maximum and minimum pressure each day,—the maximum occurring at the period of greatest cold, and the minimum at the period of greatest heat. And as regards vapor in the atmosphere, the barometer is subject to two maxima and minima of pressure—the maxima occurring at 10 A.M., when, owing to the rapid evaporation, the accumulation of vapor near the surface is greatest, and about sunset, or just before dew begins to be deposited, when the relative amount of vapor is great; and the minima in the evening, when the deposition of dew is greatest, and before sunrise, when evaporation and the quantity of vapor in the air is least.

Thus the maximum in the forenoon is brought about by the rapid evaporation arising from the dryness of the air and the increasing temperature. But as the vapor becomes more equally diffused, and the air more saturated, evaporation proceeds more languidly; the air becomes also more expanded by the heat, and flows away to meet the diurnal wave of cold advancing from the eastwards. Thus the pressure falls to the afternoon minimum about 4 P.M. From this time the temperature declines, the air approaches more nearly the point of saturation, and the pressure being further

increased by accessions of air from the warm wave, now considerably to the westward, the evening maximum is attained. As the deposition of dew proceeds, the air becomes drier, the elastic pressure of the vapor is greatly diminished, and the pressure falls to a second minimum about 4 A.M.

The amount of these daily variations diminishes from the equator towards either pole, for the obvious reason that they depend, directly, or indirectly, on the heating power of the sun's rays. Thus, while at the equator the daily fluctuation is 0.125 inch, in Great Britain it is only a sixth part of that amount. It is very small in the high latitudes of St. Petersburg and Bossekop; and in still higher latitudes, at that period of the year when there is no alternation of day and night, the diurnal variation probably does not occur. In the dry climate of Barnaul, in Siberia, there is no evening maximum; the lowest minimum occurs as early as midnight, and the only maximum at 9 A.M.

Since the whole column of the atmosphere, from the sea-level upwards, expands during the heat of the day, thus lifting a portion of it above all places at higher levels, it is evident that the afternoon minimum at high stations will be less than at lower stations, especially when the ascent from the one to the other is abrupt. Thus, at Padua, in Italy, the afternoon minimum is 0.014 inch, but at Great St. Bernard it is only 0.003 inch.

Annual Variation.—When it is summer in the one hemisphere, it is winter in the other. In the hemisphere where summer prevails, the whole air, being warmer than in the other hemisphere, expands both vertically and laterally. As a consequence of the lateral expansion there follows a transference of part of the air from the warm to the cold hemisphere along the earth's surface; and, as a consequence of the vertical expansion, an overflow in the upper regions of the atmosphere in the same direction. Hence, in so far as the dry air of the atmosphere is concerned, the atmospheric pressure will be least in the summer and greatest in the winter of each hemisphere. But the production of aqueous vapor by evaporation being most active in summer, the pressure on the barometer will be much increased from this cause. As the aqueous vapor is transferred to the colder hemisphere it will be there condensed into rain, and being thereby withdrawn from the atmosphere, the barometer pressure will be diminished; but the dry air which the vapor brought with it from the warm hemisphere will remain, thus tending to increase the pressure.

In the neighborhood of the equator there is little variation in the mean pressure from month to month. Thus, at Cayenne, the pressure in January is 29.903 inches, and in July 29.957 inches.

At Calcutta, 22° 36′ N. lat., the pressure is 29.408 in July, and 30.102 in January, thus showing a difference of 0.694; and at Rio de Janeiro, 22° 57′ S. lat., it is 29.744 in January (summer), and 29.978 in July (winter), the difference being 0.234. The large annual variation at Calcutta is caused jointly by the great heat in July, and by the heavy rains which accompany the south-west monsoons at this season; while in January the barometer is high, owing to the north-east monsoons, by which the dry cold dense air of Central Asia is conveyed southward over India.

At places where the amount of vapor in the air varies little from month to month, but the variations of temperature are great, the difference between the summer and winter pressures are very striking. Thus, at Barnaul and Irkutsk, both in Siberia, the pressures in July are respectively 29.243 and 28.267, and in January 29.897 and 28.865, the differences being upwards of six-tenths of an inch. The great heat of Siberia during summer causes the air to expand and flow away in all directions, and the diminished pressure is not compensated for by any material accessions being made to the aqueous vapor of the atmosphere; and, on the other hand, the great cold and little rain in that region during winter causes high pressures to prevail during that season. The same peculiarity is seen, though in a modified degree, at Moscow, St. Petersburg, and Vienna.

At Reykjavik, in Iceland, the pressure in June is 29.717, and in December 29.273; at Sandwich, Orkney, 29.775, and 29.586; and at Sitcha, in

Russian America, 29.975, and 29.664. In all these places the distribution of the pressure is just the reverse of what obtains in Siberia, being least in winter and greatest in summer. The high summer pressures are due to the cool summer temperatures as compared with surrounding countries, thus causing an *inflow from these regions*, and to the large amount of vapor in the atmosphere, thus still further raising the barometric column. On the other hand, the low winter pressures are due to the comparatively high winter temperatures causing an *outflow towards adjoining countries*, and the large winter rainfall, which by setting free great quantities of latent heat, still further augments and accelerates the outflow.

The variations in mean pressure are very slight, and not marked by any very decided regularity in their march through the seasons, at Dublin, Glasgow, London, Paris, and Rome. As compared with Barnaul and Reykjavik their temperature is at no season very different from that of surrounding countries, and the vapor and rainfall are at no time much in excess or defect, but are more equally distributed over the different months of the year.

At the Great St. Bernard, 8174 feet above the sea, the pressure in summer is 22.364 inches, while in winter it is only 22.044. At Padua, there is scarcely any difference in the pressure between summer and winter. The increase in the summer pressure at the Great St. Bernard is no doubt due to the same cause already referred to in art. 65—viz., the expansion of the air upward during the warm summer months, thus raising a larger portion of it above the barometer at the highest station. But at St Fe de Bogota, 8615 feet high, near the equator, and where, consequently, the difference between the temperature in July and January is very small, the difference in the pressures of the same months is also very small, being only 0.035.

Distribution of Atmospheric Pressure over the globe, as determined by the Annual Means.—Though much additional observation is required, especially in Africa, Asia, and South America, before the isobarometric lines can be laid down on a map of the world, yet many important conclusions regarding the mean barometric pressure have been arrived at from the results already obtained. We have seen that the daily and monthly variations of pressure observed at different places are modified by the variations of the temperature of the air, the amount of vapor, and the rainfall. Since these are in their turn greatly modified by the unequal distribution of land and water on the earth's surface, we should expect to find the pressure, and the variations in the pressure, most regular in the southern hemisphere. Accordingly, there is a remarkable regularity observed in the distribution of the pressure from about 40° N. lat. southwards to the Antartic Ocean, with the exception of the region of the monsoons in Southern Asia.

The mean pressure in the equatorial regions is about 29.90; at 20° N. lat. it rises to 30.00, and at 35° N. lat. to 30.20, from which northwards the pressure is diminished. The same peculiarity is seen south of the equator, but it is not so strongly marked. At 45° S. lat. it falls to 29.90, and from this southwards it continues steadily and rapidly to fall to a mean pressure of 28.91 at 75° S. lat. This extraordinary depression of the barometer in the Antarctic Ocean, being one inch less than at the equator, and 1.326 inches less than at Algiers, is perhaps the most remarkable fact in the meteorology of the globe.

The pressure in the north temperate and frigid zones is in striking contrast to the above. From Athens, in a north-eastern direction, a high isobarometric line traverses Asia, passing in its course Tiflis, Barnaul, Irkutsk, and Yakutsk. To the east of the northern, part of this area of high mean pressure around the peninsula of Kamtschatka, there is a region of low barometer, the mean pressure being only 29.682. There is another remarkable area of low pressure around Iceland, the center being probably in the south-west of the island near Reykjavik, where the mean is 29.578. As observations are more numerous in Europe and North America, the dimensions of this depression may be defined with considerable precision by drawing the isobarometric of 29.90, which is about the mean atmospheric pressure. This line passes through Barrow Straits in North America, thence

south-eastward toward Newfoundland, then eastward through the north of Ireland, the south of Scotland, and the south of Sweden, whence it proceeds in a north-easterly direction to Spitzbergen. The following mean annual pressures will show the nature of the depression:—New York, 30.001; Paris, 29.988; London, 29.956; Glasgow, 29.863; Orkney, 29.781; Bergen, 29.804; Spitzbergen, 29.794; Reykjavik, 29.578; Godthaab in S. Greenland, 29.605; Upernavik in N. Greenland, 29.732; and Melville Island, 29.807. A depression also occurs in India, where the mean is only about 29.850, whereas in the same latitudes elsewhere it is about 30.100.

There are thus four areas of low pressure on the globe, the extent of each being nearly proportioned to the depth of the central depression—viz., Antarctic Ocean, the least pressure being 28.910; Iceland, 29.578; Kamtschatka, 29.682; and India, 29.850; and three areas of high pressure, one lying between latitudes 20° and 40° N., another between 15° and 35° S., and the third in Central Asia, from south-west to north-east. These low mean pressures are by no means constant in all cases during the months of the year. In the Antarctic Ocean they are nearly constant during the months, with perhaps a slight tendency to an increase in winter. In the region of low pressure round Iceland, the pressure is a little less than elsewhere in summer; but in winter, when the rainfall is heaviest, it is very much less, being 0.251 inch less in winter than in summer, at Reykjavik, and 0.189 at Sandwich, in Orkney. Similarly at Petropaulovski, in Kamtschatka, the pressure in winter is 0.323 less than in summer. Hence the low mean annual pressures in the North Atlantic and the North Pacific are chiefly brought about by the low pressure during the cold months of the year, and are doubtless caused by the copious rainfall during that season. On the other hand, in Southern Asia, the lowest pressures occur in summer. Thus, at Calcutta it is 29.408 in July, while in January it is 30.102—the average pressure for that degree of north latitude. Hence, in Hindostan, the low mean annual pressure arises from the very low pressure in summer caused by the heavy rains falling at that season, particularly on the south slope of the Himalayas. Generally the pressure is low wherever a copious rainfall prevails over a considerable portion of the earth's surface, owing to the large quantity of caloric set free as the vapor is condensed into rain.

It is scarcely necessary to point out how important it is to keep in mind these facts of the pressure of the atmosphere, it being evident, for instance, that a pressure of 29.00 in the North Atlantic would portend stormy winds, while the same pressure south of Cape Horn, being the mean pressure there, would indicate settled weather.

The readings of the mercurial barometer are subjected in nice observations to several corrections:

1st. To 32° F. allowance being made for expansion of both mercury and scale for all observations above that temperature. A barometric pressure of thirty inches at 32° would be indicated by a height of $30\frac{1}{10}$ inches at 70°.

2d. For decrease of gravitation at stations above the level of the sea, acting on both the mercury and the air.

3d. For increase of gravity with increase of latitude.

4th. For temperature of air; the density decreasing as temperature rises.

5th. For humidity of the air which also influences its density.

6th. For capillary attraction of the tube.

The Aneroid requires when properly constructed a less number of corrections.

Many of them are so compensated as to require no correction for temperature of the instrument.

A correction for temperature of the air above or below some conventional standard is the only one usually applied to the best aneroids, and the corrections for decreased force of gravity and for humidity are the only other corrections required for the most refined observations.

MEASUREMENT OF ALTITUDES.

It is in the measurement of heights that the aneroid is most highly appreciated. Its portability and the ease and

rapidity with which it affords accurate results, render it one of the most satisfactory of scientific instruments.

The text books in physics present formulas for computing heights from barometric observations, based on physical laws which we will briefly give.

If the density of the air were constant throughout, the measurement of heights would be a problem of the simplest character; for as mercury weighs 10,500 times as much as air at the sea level, the mercurial column would fall one inch for every 10,500 inches of ascent above the sea. But air is compressible, and, in accordance with Boyle's law, its density varies with the pressure to which it is subjected.

Now suppose the atmosphere divided into layers of uniform thickness, but so thin that the density may be considered uniform throughout.

Let h = the thickness of each layer.

W = weight of a cubic foot of air at pressure H.

W_1 = weight of a cubic foot of air at H.

H_0 H_1, &c. = pressures measured in inches of mercury.

Then the pressure upon the unit of surface of any layer is greater than that upon the surface of next higher layer by the weight of a volume of air whose base is the unit of surface and whose height is the thickness of the layer. If one foot be the unit of surface, then this quantity would be hW. And to express it by height of mercury column, it is necessary to multiply by $\frac{30}{2157}$ which gives $\frac{h\mathrm{W}30}{2157}$

But $\mathrm{W} : \mathrm{W}_0 :: \mathrm{H} : 30$

W_0 being the weight of a cubic foot air at the level of the sea (=.0807 at 32° F).

We have from the above $\mathrm{W} \times 30 = \mathrm{W}_0 \times \mathrm{H}$, and the above expression for diminution may be written $\frac{h\mathrm{W}_0\mathrm{H}}{2157}$.

If H_0 H_1 H_2 represent the pressures at the surfaces of the successive layers, we shall have

$$H_1 = H_0 - \frac{h\mathrm{W}_0 H_0}{2157} = H_0 \left(1 - \frac{h\mathrm{W}_0}{2157}\right)$$

$$H_2 = H_1 - \frac{h\mathrm{W}_0 H_1}{2157} = H_1 \left(1 - \frac{h\mathrm{W}_0}{2157}\right)$$

$$H_3 = H_2 - \left(1 - \frac{h\mathrm{W}_0}{2157}\right)$$

$$H_n = H_{n-1} \left(1 - \frac{h\mathrm{W}_0}{2157}\right)$$

Multiplying these equations and suppressing common factors, we get

$$H_n = H_0 \left(1 - \frac{h\mathrm{W}_0}{2157}\right)^n$$

If h be taken at one foot then n would represent the number of feet vertically between two stations at which the barometric pressures are H_n and H_0 respectively.

By substituting for W_0 its value and taking logarithms we have

$$\log. \frac{H_0}{H_n} = n. \log. \left(\frac{2157}{2156.9193}\right)$$

whence

$$n = 60135.4 \times \log. \frac{H_0}{H_1}$$

For use in accurate observations, corrections are required for temperature, humidity and variation in the force of gravity.

QAUY WALLS AT ROTTERDAM.

From "Deutsche Bauzeitung."

Opposite the town of Rotterdam, on the left bank of the Meuse, is the peninsula of Feijenoord, occupied by a large shipbuilding and iron-works company, by a station of the Dutch State railway, and by private and public buildings in

connection with the trade of the port. The railway possesses a large dock, the "Spoorweghaven," 1,312 yards long and 109 yards wide. The Rotterdam Trading Company is now constructing a second basin about 1,092 yards long and from 43 feet to 82 feet wide. Both these docks are open or tidal basins; the average rise of the tide is only 3 feet 7 inches; the lowest tide in 1872 was 2 feet 9½ inches below zero, and the highest spring tide 5 feet 11½ inches above zero, the extreme range is therefore nearly 9 feet.

The flood tide runs for four hours, the ebb therefore about eight hours twenty minutes; the current is not strong. The nature of the soil is most unfavorable. Piles, 62 feet, 4 inches long, were driven without reaching solid ground; the soil is hardly strong enough for ordinary banks, and good sand has to be brought from a distance. It was, therefore, impossible to erect substantial quay walls on a masonry substructure, and piling was chosen as the only means of securing a permanent foundation. The construction adopted for the new basin is almost the same as the one used for the Spoorweghaven, and is intended not only to secure the bank, but also to supply a wide quay, and considerable storage room for raw products and other goods.

The bottom of the basin is 19 feet 8 inches below zero, the top of the quay wall 9 feet 2 inches above it, the natural surface of the ground being about 9 feet 10 inches below zero. First, a wide ditch was dredged out to 23 feet below zero, with a slope of 1 to 1 both ways: this was filled with sand as soon as the mud was got out. Eight rows of piles were then driven, 4 feet 4 inches apart from center to center both ways, the front row being in line with the intended quay wall. These piles were from 52½ feet to 65½ feet long, and were cut off at the level of 4 feet 3 inches below zero. At a level of 11 feet 6 inches below zero, strong longitudinal bracing was introduced on both sides of each row of piles, and on the inside of the fourth row from the front a complete longitudinal wall of planks, ¼ inch thick, was erected parallel to the face, in order to ease the thrust on the front piles. Similar cross walls were run from this to the face at every third row of piles, thus dividing the front half of the quay into a number of small compartments. The object of this was to diminish the effect of the current on the material of the slope, which was then completed from the level of 11 feet 6 inches below zero down to the bottom of the basin, and protected by a slight face and footing of stones. A substantial grid was constructed on the piles, and a platform of double planking, 3.15 inches thick, laid on it, braced horizontally above and below. The masonry wall was commenced over the whole width of 29 feet 6 inches, and carried up to a height of 1 foot 7 inches; the remainder of the height was, however, to be used as a warehouse. The foundations were stepped off in front and rear, so as to leave a face wall of 3 feet 11 inches thick at 1 foot 7 inches below zero, and a rear wall of 2 feet 6 inches at the same level.

The remaining clear space of 22 feet 7 inches was divided into three parallel galleries, by rows of columns resting on masonry, also stepped up from the foundations, so that the vertical section of the whole quay shows, roughly, two right-angled triangles on the face and rear, and two isosceles triangles filling up the space between them, and capped by the columns. The intervals between these triangles were filled up to a level of foot 7 inches below zero, for the floor of the warehouse. The columns consist of 4-inch gas-pipes filled with cement, resting on square cast-iron ribbed bed-plates, supplied with similar cast-iron caps. The latter carry rolled cross and longitudinal girders on which the road is laid. The Author indicates a batter of both face and rear walls, but the sketch is on too small a scale for the dimensions to be measured. After the completion of the masonry foundation, the slope was finished under the grid up to the fourth row of piles, and was covered with stones; earth was filled in behind up to the zero mark, and the rest of the basin was excavated.

The Author calculates the extreme load which can possibly come on each pile, and estimates it at 116 cwt.; which, reduced to square inches, and assuming the piles to average 12 inches diameter, is almost exactly 1 cwt. per square inch.

FOUNDATIONS.*

By JULES GAUDARD, Civil Engineer.

From Proceedings of the Institution of Civil Engineers.

II.

Cylindrical foundations are sunk with or without the aid of compressed air according to circumstances. These foundations possess the two great advantages of being capable of being sunk to a considerable depth, and of presenting the least obstruction to the current.

In a clay soil the cylinder acts as a movable cofferdam, which is sunk by being weighted, and enables the foundations inside to be built up easily and cheaply. This method was first adopted by Mr. Redman, M. Inst. C. E., at Gravesend; and afterwards at the Charing Cross and Cannon Street bridges; and also for the piers of the Victoria bridge over the Thames. Iron cylinders are preferred in certain cases to cylinders of brick, masonry, or concrete, on account of the ease with which they are lowered in deep water on to the river bed; in spite of the disadvantages attaching to them of high price, of the considerable weights required for sinking them, and lastly, of being only cases for the actual piers.

In 1823, Sir Mark Brunel, in sinking the wells of access to the Thames Tunnel used linings of brickwork, 50 feet in diameter, and resting on iron frames with vertical tie-rods. At Rochefort, M. Guillemain used linings of masonry resting on plate-iron rings and strengthened by iron chains; the wells were made sometimes 10 feet, sometimes 13 feet in diameter, and it was found that the facility and rate of descent of the larger linings more than compensated for the additional material. At Lorient the Caudan footbridge was built on four large rectangular frames, sunk from 50 to 60 feet below high water. When the ground is very soft it has a tendency to run into these tubular cofferdams when the water is pumped out.

The method of sinking wells in India has been previously referred to. Mr. Imrie Bell, M. Inst. C. E., added a pole to the jham used by the natives to save the trouble of diving, but even with this addition the process was slow. The foundations of the Poiney viaduct, on the Madras railway, were put in by this method. In more recent works the curb was made of iron instead of wood, and angular as in the case of the Jumna bridge. The first lengths were short, 5 to 6 feet, to insure a vertical descent; then a length of 10 feet, and afterwards lengths of 13 and 16 feet were added.

At the Glasgow bridge the lining was of cast-iron rings, being easier to lower in mid-stream; but for the quays and docks on the Clyde linings of brickwork and concrete were adopted for the sake of economy. Mr. Milroy, Assoc. Inst. C.E., considers that with concrete, which can be moulded to an edge at the bottom, all metal additions may be omitted where only silt or sand have to be traversed, and that the bottom ring should be of iron for penetrating harder soils. In the Clyde extension works the wells were filled up with concrete, and a double row of cylinders of 9 feet diameter were adopted in preference to a single row of 12 feet. It would be possible in this arrangement to take out the sand between the adjacent cylinders and form them into a solid mass by filling up these interstices with concrete. Mr. Ransome used cylinders of "apænite" for the Hermitage wharf on the Thames.

The Dutch engineers have often used oval-shaped iron tubes sunk by dredging inside. Thus in the bridge on the North Sea Canal the piers are elliptical; the one on which the opening portion turns having axes of 23 and 18 feet, and the others axes of 39½ and 14 feet. The horizontal flanges and ribs were larger where the radius of curvature is increased, and the vertical ribs are not continuous, but arranged so as to overlap. The bridge over the Yssel, on the Utrecht and Cologne railway, rests upon cylinders which were sunk by internal dredging 17¾ feet below the river bed.

* Translated from the French by L. F. Vernon-Harcourt, M.A., M. Inst. C.E.

In France sinking cylinders by dredging is not often resorted to in rivers, possibly owing to a failure of this system at Perpignan, where the sinking of a masonry cylinder by dredging was stopped by boulders, and compressed air had to be used. However, the foundations of bridges at Rivesaltes, and over the Saône at Lyons, and the jetty made at Havre in 1861, were executed by this method. For the walls of the wet dock of Bordeaux rectangular wells have also been sunk by dredging.

The extension of the system must depend chiefly on improvements in the dredging machinery, of which the successive steps in advance already attained may be noted.

The jham was suspended by Kennard's sand pump. With this machine a well, 12½ feet in diameter, was sunk in the Jumna 8 to 10 inches per hour by fourteen workmen. As the Kennard pump was not able to work in the compact clays and conglomerate met with in rebuilding the bridges over the Beas and the Sutlej Bull's dredger was adopted, which consists of a semi-cylindrical case with jaws opening in two quadrants, like the American dredger of Morris and Cummings.

Mr. Stone, M. Inst. C.E., however, mentions that when it met with a hard stratum a descent of only 2 feet 10 inches was accomplished in three months, whereas in the upper layer the progress was much more rapid than with the sand-pump.

Next came Mr. Milroy's "excavator,' consisting of an octagonal frame from which are suspended eight triangular spades. These spades are forced vertically into the ground and are then lifted by chains so as to come together and inclose the earth, which can then be raised and discharged.

At the Glasgow bridge the progress was, on an average, 11½ feet per day, and the maximum 20 feet. At Plantation Quay the average for a cylinder was about 4 feet per day, but these cylinders were impeded in their sinking by tongues and grooves, so that double this rate might be reckoned on for unconnected cylinders. Another machine is the "screw pan" used at the Loch Ken viaduct, a conical perforated vessel, the diameter at the top being 2 feet, and furnished at the bottom with a screw which enters the ground when turned.

The sand and mud entering the vessel are retained by little leather valves when the instrument is lifted. It works well in silt and clay; in harder soils a smaller vessel is needed.

Lastly there is the "boring head" used by Mr. Bradford Leslie, M. Inst. C.E., at the Gorai bridge. A revolving plane with blades underneath, able to disintegrate hard clays and compact sand, is worked inside the cylinder, and at the same time the excavated material is drawn up and removed from the cylinder by a siphon. To maintain an upward pressure in the siphon the level of the water in the cylinder is always kept higher than in the river. The boring-head made one revolution in about one minute and a half or two minutes, and excavated through clayey and sandy silt at a rate of about 1 foot per hour. One advantage possessed by this system is that the rate of progress is independent of the depth. The side piers of the Gorai bridge were sunk 124 feet below the surface, and the river piers 98 feet below low-water level. The only bridge the foundations of which have been carried down as deep as those of the Gorai bridge is the St. Louis bridge over the Mississippi; but the method of compressed air used in this work, looking at the difficulties and loss of life attending it, would have been impracticable with coolie labor at Gorai. The system of sinking by dredging is generally to be preferred to the compressed air system, except where numerous obstacles, such as boulders or embedded trees, are met with.

The friction between cylinders and the soil depends on the nature of the soil and the depth of sinking. For cast iron sliding through gravel the co-efficient of friction is between 2 and 3 tons on the square yard for small depths, and reaches 4 or 5 tons where the depth is between 20 and 30 feet. In certain adhesive soils it would be more. In sinking the brick and concrete cylinders in the silt of the Clyde it was found to amount to about 3½ tons per square yard.

Passing on to the consideration of the pneumatic systems, the process of Dr. Potts was one of the first employed for sinking tubular foundations by the help

of air. The cylinder in process of being sunk was connected with a vessel in which a vacuum was produced, and a communication between them being suddenly made a shock was produced by the rush of air. By this means Mr. Cowper, M. Inst. C.E., succeeded in driving down cylinders 5 feet at a time. The only novelty in the system was using air for applying a downward pressure on the cylinder, as dredging had still to be resorted to for removing the earth from the inside, and, moreover, there was a considerable influx of the surrounding soil, and frequent divergencies from the perpendicular. Mr. Bramwell, M. Inst. C.E., observing the effects produced by the rush of air out of the cylinder, in an aqueous soil, suggested sinking by forcing water from the interior of the cylinder towards its external surface, a process which would disintegrate the earth lubricate the sliding cylinder, and prevent the influx of the soil. The difficulties of the Potts process increase with the size of the cylinder; and for sinking the cylinders, 10 feet in diameter, of the Shannon bridge it was abandoned after an unsuccessful attempt.

The method of compressed air for enabling operations to be conducted under water is merely a modification of the diving-bell; but the application of it to a cylinder forced down by undermining was first made, in 1839, at Chalons for working a coal seam rendered inaccessible by the infiltrations of the Loire. After having begun the shaft by beating down a cylindrical lining of sheet iron, $3\frac{3}{8}$ feet in diameter, it occurred to the engineer, M. Triger, to cover over the top of the cylinder, and by forcing air in to drive out the water and admit the workmen. An air chamber was formed at the top with double doors, serving as a sort of lock for the passage in and out of the cylinder of men and materials without giving an outlet to the compressed air, and a pipe running up the cylinder carried off the water from the bottom. In 1845 M. Triger sank another cylinder, 6 feet in diameter, in the same way, and suggested the employment of the method for the foundations of bridges.

The first bridge foundations of this kind were carried out, in the years 1851–52, at the Rochester bridge on the Medway, which has masonry piers each supported on fourteen cylinders, 6 feet 11 inches in diameter, filled with concrete. Having begun with the Potts process till on alighting on old foundations it proved useless, Mr. Hughes, M. Inst. C.E., conceived the notion of reversing the current of air, and sinking the cylinders by the help of compressed air. The success of this method recalled to mind earlier suggestions in the same direction, such as the patent of Lord Cochrane, in 1830, for excavating foundations by compressed air, and the suggestion of M. Colladon of Geneva to Sir M. Brunel to try to stop the rush of water into the Thames Tunnel by forcing in air.

At the Chepstow bridge foundations the late Mr. I. K. Brunel, Vice-President Inst. C.E., abandoned the Potts process on coming upon an embedded tree, and resorted to compressed air, which he also subsequently employed in commencing the foundations of the iron cofferdams used for the piers of the Saltash bridge.

The various details of the compressed air system are given in the descriptions of the works in which it has been employed. Theoretically, when the lower edge of the cylinder has reached a depth of h feet below the surface of the water, the pressure required for driving the water out of the excavations is $\frac{3.14}{h}$ atmospheres; but frequently the intervention of the ground between the bottom of the river and the excavation enables the work to be carried on at a less pressure, as Mr. Brunel did at Saltash. A considerably greater pressure would be required if the water had to be forced from the excavation through the soil below the river bed; but this is avoided by placing a pipe inside to convey away the water, and M. Triger has found that the lifting of the water was facilitated by the introduction of bubbles of air into the pipe at a certain height.

Pressures of 2 or even up to 3 atmospheres do not injure healthy and sober men, and suit best men of a lymphatic temperament, but prove injurious to men who are plethoric or have heart disease. It is advisable to avoid working in hot weather, and each workman should not work more than four hours per day, or more than six weeks consecutively. At

Harlem, New York, however, workmen have remained ten hours under a pressure of 50 feet, and even 80 feet of water. On the other hand, at St. Louis under a pressure of little more than 3 atmospheres several men were paralyzed or died, and the period of work was gradually reduced from four hours to one hour. From experiments on animals M. Bart has found that the accidents caused by a sudden removal of pressure are due to the escape of the excess of gas absorbed by the blood. Beyond 6 atmospheres any sudden return to the normal pressure is attended with danger; the usual rule now is to allow one minute per atmosphere. The cylinders subjected to pressure should be furnished with safety valves, pressure gauges, and alarm whistles, as explosions occasionally occur.

Iron rings from 6 feet to 13 feet in diameter are cast in one piece, and a caoutchouc washer is introduced at the joints between the rings; cylinders of larger diameter are cast in segments, and cylinders of smaller diameter than 6 feet are rarely used. The thickness is usually $1\frac{1}{8}$ inch, increased to $1\frac{1}{2}$ inch or $1\frac{7}{8}$ inch were exposed to blows, in conical joining lengths, and in the bottom length.

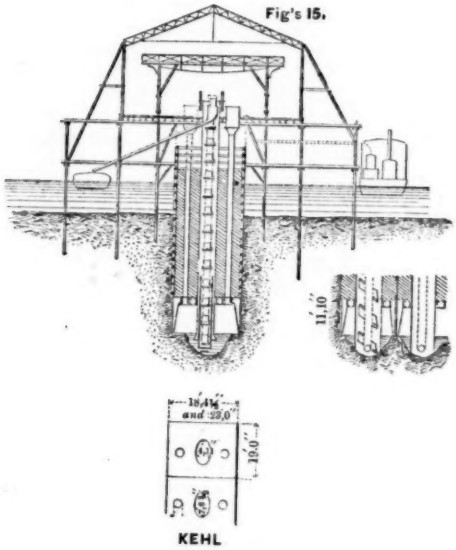
When two cylinders have to be sunk close together it is best to sink them alternately, as they tend to come together when sunk at the same time. At Macon, where there was only an interval of $3\frac{1}{4}$ feet between two cylinders, one of the cylinders was seen to rise suddenly as much as 6 feet when the other was forced down. Sometimes where cylinders of small diameter have to be used the excavations are extended beyond the cylinder at the bottom, and filled with concrete to give a greater bearing surface; this plan was adopted at Harlem bridge, New York, and by the late Mr. Cubitt, Vice-President Inst. C.E., at the Blackfriars railway bridge. Another way of accomplishing the same object is by enlarging the lower rings of the cylinder, and putting in a connecting conical length, as was done by Sir John Hawkshaw, Past-President Inst. C.E., at the Charing Cross and Cannon Street bridges.

The cylinders at Bordeaux were forced down by MM. Nepveu and Eiffel, in 1859–60, by strong beams of wrought iron, moved up or down by the pistons of four hydraulic presses, having 11 feet length of stroke and exerting a pressure of 60 to 70 tons; the force could be applied at pleasure, and regulated according to circumstances. At Argenteuil, where cylinders 12 feet in diameter had to be sunk, the concreting inside was carried on during the sinking, leaving only a circular shaft in the center, 3 feet 7 inches in diameter, lined with wooden framing, and enlarged at the bottom to a conical shape by a sort of cage of inclined beams butting against the bottom of the shaft (Fig. 18). The cylinders were sunk 50 feet on the average below low-water level, through mud, sand, gravel, and clay, on to marl or limestone, and four screw-jacks of 20 tons power supported the bottom ring by means of flat iron straps. After the sinking was completed the chamber at the bottom was filled with cement concrete, poured around iron pipes placed near the sides so as to maintain the pressure of air during the operation. When this layer of concrete was set the pipes were closed with cement, the normal pressure restored, and the shaft filled up with concrete. Concrete deposited under compressed air appears to set quicker, and to increase somewhat in strength, provided it is deposited in thin layers allowing the excess of water to escape. At Szègedin this was effected by mixing very dry bricks with the concrete. At Perpignan the foundations of a bridge over the Tet had been commenced by sinking a masonry cylinder by dredging inside, but large stones being unexpectedly met with the method of compressed air had to be resorted to. The masonry cylinder, $3\frac{1}{4}$ feet thick and 13 feet outside diameter, with a batter outwards of 1 in 100, was lined inside with neat cement, and was covered with a plate-iron top $\frac{1}{8}$ inch thick. The sinking was assisted when necessary by letting out air; the depth attained was about 26 feet. The cylinder was filled with concrete, which for the first $6\frac{1}{2}$ feet was deposited under pressure. The success attending this experiment has led M. Basterot to recommend the deliberate application of compressed air to masonry cylinders for depths of less than 33 feet below water, and he estimates the cost

of such a cylinder, 13 feet in diameter, sunk by this method 26 feet deep and filled in, at £340.

The foundations of the piers of the Kehl bridge were accomplished by the engineers, MM. Fleur Saint-Denis and Vuigner, by a combination of the principles of the compressed air process, the sinking of a pier by its own weight, the sinking by dredging, and the cofferdam system. As the bed of the Rhine at Kehl consists of large masses of gravel liable to be disturbed to a depth of 55 feet below low-water level, it was deemed advisable to carry the foundations down about 70 feet below low water. For the two central piers the chamber of excavation was divided into three caissons, the length of each being 18 feet 4 inches, the width of the foundation. For the piers forming the abutments for the swing bridges there were four caissons, each 23 feet long, the breadth of all the caissons being 19 feet. The plate iron forming the caissons was $\frac{3}{8}$ inch thick at the top, and $\frac{5}{16}$ inch thick at the sides, and strengthened by flanges and gussets. The top was strengthened by double T beams for supporting the weight of the masonry above. There were three shafts to each caisson, two being air shafts, 3¼ feet in diameter, one being in use whilst the other was being lengthened or repaired; the other shaft in the center was oval, open at the top and dipping into the water in the foun-

Fig's 15.

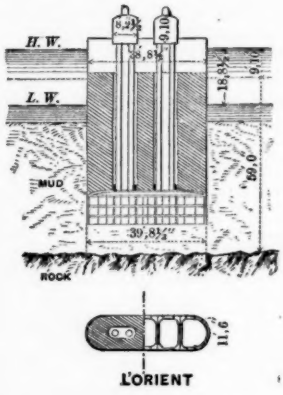


dations at the bottom, so that the water could rise in it to the level of the river. In this shaft a vertical dredger with buckets was always working, and the laborers had only to dig, to regulate the work, and remove any obstacles. The screw-jacks controlling the rate of descent had a power of 15 tons, and were in four pairs. The wooden framing serving as a cofferdam was erected above the chamber of excavation; it was useful at the commencement for getting below the water, but might subsequently have been dispensed with. It was also found by experience that the caissons were sunk better in one division than in several divisions, and doors of communication were accordingly made through the double partitions. The iron linings to the air shafts were removed before the shaft was filled up. The shaft containing the dredger was at first made of iron, but afterwards of brick for the sake of economy. The sinking occupied sixty-eight days for one abutment, and thirty-two days for the other, giving a daily rate of 1 foot 1 inch and 1 foot 8½ inches respectively. The sinking of

the caissons for the intermediate piers took twenty to thirty days, which gives a daily rate of two feet $7\frac{1}{2}$ inches (Fig. 15).

For large works, where the load on the foundations is considerable, carrying down the foundations to a hard bottom is much better than piling. The dredger used at Kehl cannot be regarded as universally applicable. Some soils are not suitable for dredging, and in other cases the small amount of excavation renders the addition of an extra shaft inexpedient, as for instance at Lorient. The chamber of excavation is almost invariably made of plate iron, but, unlike those at Kehl, with the iron beams above the ceiling, instead of below, so that the filling in may be accomplished more easily. The cutting edge is always strengthened by additional plates. At Lorient the thickness was $2\frac{3}{16}$ inches, with several plates stepped back so as to form a sort of edge; the sides were about $\frac{1}{2}$ inch thick at the bottom, and $\frac{5}{16}$ inch at the top, and the roof was curved a little to increase its strength. At Vichy the plates were about $\frac{1}{4}$ inch thick. At La Voulta, Hollandsch Diep, and Lucerne, a sort of masonry lining was placed against the iron plates, and kept in place by gusset plates, to afford greater rigidity against the pressure of the earth. At St. Maurice wooden struts were substituted for angle-iron flanges; and at Vichy struts were put in at the base of the caisson, and also half-way up to support the sides. In consequence of these modifications, the caisson at Lucerne ($55\frac{3}{4}$ feet by $13\frac{3}{4}$ feet) weighed only 28 tons; the caisson at St. Maurice ($32\frac{3}{4}$ feet by $14\frac{1}{2}$ feet) weighed 14 tons; whereas at Kehl, a caisson, 23 feet by 19 feet, weighed 34 tons; at Lorient ($39\frac{1}{3}$ feet by $11\frac{1}{2}$ feet) weighed $27\frac{1}{2}$ tons; and at Riga ($64\frac{1}{3}$ feet by 16 feet) weighed $45\frac{3}{4}$ tons. The height of the chamber of excavation should be about 8 feet 10 inches. Frequently the cofferdam casing is of iron, as at Kehl, which protects the newly-built masonry from friction; and the upper portion of the casing can be removed when the work is completed. In a sea bed, with a silty bottom, special precautions must be taken against overturning, as variations in weight, according to the depth of immersion, are added to the effects of the current. Some divergence from the perpendicular at Lorient was due partly to this cause, but partly also to the absence of supporting screw-jacks. At Lorient there were two air locks, each connected with two shafts, in which balanced skips went up and down (Fig. 16). On the top of the bottom caisson a casing of sheet iron, from $\frac{3}{16}$ to $\frac{1}{8}$ inch thick, and weighing about 15 tons, was erected in successive rings. At the Nantes bridges, built in 1863 by M. M. Gouin for the railway of Roche-sur-Yon, twenty-two caissons were erected, and the depth of the concrete foundations varied from 39 to 62 feet. The same firm were the contractors for the pneumatic foundations at Hollandsch Diep for three piers, two being carried about 80 feet below high-water level, and the other 65 feet. As the river bed was very soft down to 50 feet below high water, and injury from storms might be apprehended, it was necessary to perform the first part of the sinking as rapidly as possible. The working chambers, and the lower 16 feet of the caisson, and the shafts for 23 feet in height, were erected on the bank, and masonry built on the horizontal projections of the chambers. Each caisson was then slid down an inclined plane to low-water mark, and at high water two boats fastened together removed them to their proper site, where they were deposited and gradually sunk into the ground. The excavation, the building up of the masonry, and the addition of successive

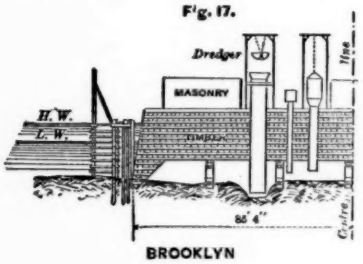
Fig's 16.



lengths to the caisson, were carried on simultaneously. As the earthwork was easily removed, the caissons sank at a rate of from 1½ foot to 3¾ feet per day. The first two piers were each completed in forty-five days from the launching of the caissons.

The Americans have adopted the pneumatic system for some large works, and introduced improvements. At the St. Louis bridge the foundations were carried to a greater depth than had ever been previously attained; and at East River bridge compressed air was used in wooden caissons of large dimensions. The particulars of the St. Louis bridge have been given by Mr. Francis Fox, M. Inst. C.E. The hydraulic sand pumping tube of Mr. Eads must only be recorded. The following details of the East River bridge are derived from the treatise of M. Malézieux, previously referred to. The Brooklyn pier was to be carried 50 feet and the New York pier 75 feet below high water. To provide against unequal sinking, owing to the variable nature of the soil, consisting of stiff clay mixed with blocks of trap rock, Mr. Roebling decided to place the bottom of the piers upon a thick platform of timber which formed the roof of the working chamber (Fig. 17). The sides were also

Fig. 17.



BROOKLYN

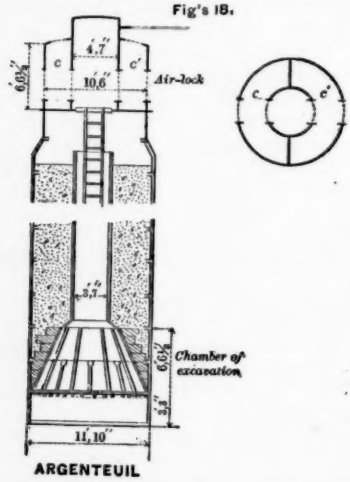
made of wood, as being easier than iron to launch and deposit on the exact site. The roof consisted of five tiers of beams, 1 foot deep, of yellow pine, placed one above the other and crossed, the beams being tightly connected by long bolts. The working chamber was 167 feet by 102 feet, and 10 feet clear height. The side walls had a ∨ section, with a cast-iron edge covered with sheet iron; the walls had a batter inside outwards of 1 to 1, and 1 in ⅒ on the outside. Five transverse wooden partitions, 2 feet thick at the bottom, served to regulate the sinking. When the caisson had been put in place, twelve tiers of beams were added on the roof of the chamber of the Brooklyn pier, and nineteen on that of the New York pier, so that the top rose above water, and the masonry could be built without a cofferdam lining. The excavation, to the extent of 19,600 cubic yards, was performed in five months by Morris & Cumming's scoop dredger, working in two large shafts, dipping into the water at the bottom, and open above. When hard soil was met with these shafts were shut, and the excavation performed by manual labor under compressed air. In the New York caisson the total number of shafts was nine. The blocks of trap rock impeded the progress considerably; they had to be discovered by boring, and shifted or broken before the caisson reached them. When under 26 feet of water they could be blown up; this enabled the rate of progress, which had been 6 inches per week, to be doubled or trebled. When the caisson had reached a compact soil, it was possible to reduce the pressure to two-thirds of an atmosphere in excess of the normal pressure, and water had occasionally to be poured into the open shafts to maintain the proper water-level in them. By frequent renewal of the air, a supply was furnished for one hundred and twenty men and for the lights; and the temperature was kept nearly constant throughout the year at 86° within the caisson, whilst in the open air it varied from 108° to 0°. As the load increased as the caisson went down, the roof of the Brooklyn caisson was eventually supported by seventy-two brick piers, so that the caisson might not become deeply embedded in the event of a sudden escape of air. In the New York caisson two longitudinal partitions were added, which served the same purpose.

In the silty sand which was frequently met with, a discharge pipe, up which the sand was forced by compressed air, proved very useful, discharging a cubic yard in about two minutes. The New York caisson (170 feet by 102 feet) was sunk in five months; the earthwork removed amounted to 26,000 cubic yards. The cheapness of wood in America per-

mits a much freer use of it there than could be attempted in Europe.

When the watertight nature of the lower soil in the foundations of the East River bridge is considered, coupled with the inconveniences experienced in working under compressed air, as shown at the St. Louis bridge, it seems probable that in some future large work it may be possible to commence sinking a large caisson with compressed air, and after a better stratum is reached open all the shafts. The operation could then be completed by pumping out the small amount of water that might come in, and excavating in the ordinary way, as is often done in England, on a small scale, where the excavation to sink the cylinders to a water-tight stratum is performed by divers. If, as M. Morandière suggests, the air-lock was placed close over the working chamber, or even inside it, which would save constant alterations and allow of its being of larger dimensions, it would be desirable to have a special air-lock at the top, so that in the event of an accident the men might run up the shaft without the delay occasioned by passing through the air-lock. At Bordeaux the air-lock was formed by fixing one circular plate at the top and another at the bottom of

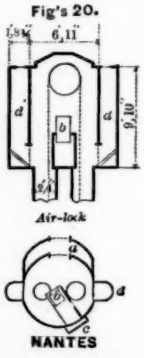
Fig's 18.



ARGENTEUIL

one of the rings of the cast-iron cylinder, so that it was unnecessary to remove it each time that an additional ring was added. To save loss of air the air-lock should be opened very seldom, or made very small if required to be opened often. At Argenteuil the air-lock had an annular form (Fig. 18) with two compartments C, C′, each having an external and an internal door. One compartment was put in communication with the interior to be filled with the excavated material, whilst the other was being emptied by the outer door, so that the loss of air was diminished without any interruption to the work. Sometimes a double air-lock with one large and one small compartment is used; the large one being only opened to let gangs of workmen pass, and the small one just big enough to admit a skip and to contain a little crane for moving it. By having a small air-lock opened frequently, any sudden alterations in pressure are diminished. A more complete arrangement was adopted at Nantes (Fig. 20). There a sheet-iron cylinder was

Fig's 20.

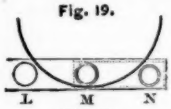


NANTES

placed on the top of the double shaft in which the skips worked, having at one side a crescent-shaped chamber, *a*, serving to pass four men, and also on either side two concrete receivers, *d*, *d′*, having doors above and below. There was also a shoot below for turning the concrete into the foundations, and a box, *b*, *c*, holding a little wagon which emerges at *c* after having been filled from an upper door, *b*. This last contrivance resembles that devised at Vichy by M. Moreaux (Fig. 19). The cast-iron box L, N, going across a segment of the air chamber, has three orifices, L, M, N, and a drawer with two compartments slides inside it. If these compartments are at M and N, the left one at M is filled whilst the

other at N is emptied. Then by a rack movement the drawer is pushed back till

Fig. 19.



VICHY

the compartment to the right comes to the center of the box, that is to say, into the air-lock, and the other is emptied outside at L. At Rotterdam, M. Michaëlis put a little inclined trough at the bottom of the principal air-lock, and closed it at each extremity by a valve, so that it both formed a little independent air-lock and also a shoot for the excavation. Mr. Smith employed the same system at the Omaha bridge over the Missouri. By not permitting the earthwork to enter the principal air-lock, it was possible to keep six great glazed bull's-eyes clean, by which both the daylight was admitted and at night the light was thrown from a reflector. The use of lamps inside, smoking and giving a bad light, was thus dispensed with.

The Author next proposes to give some details of the cost of foundations constructed by the help of compressed air. At Moulins cast-iron cylinders, 8 feet 2½ inches in diameter, with a filling of concrete and sunk 33 feet below water into marl, cost £12 18s. 6d. per lineal foot, or £6 2s. for the ironwork, and £6 16s. 6d. for sinking and concrete. At Argenteuil, with cylinders 11 feet 10 inches in diameter, the sinking alone cost £8 13s. 2d. per lineal foot, and one cylinder was sunk 53½ feet in three hundred and ninety hours; and at Orival, £7 12s. 5d., where the cylinder was sunk 49 feet in twenty days. At Bordeaux, with the same sized cylinders, a gang of eight men conducted the sinking of one cylinder, and usually 34 cubic yards were excavated every twenty-four hours. The greatest depth reached was 55¾ feet below the ground, and 71 feet below high water. In the regular course of working, a cylinder was sunk in from nine to fifteen days, and the whole operation, including preparations and filling with concrete, occupied on the average twenty-five days. One cylinder, or a half pier, cost on the average £2,320, of which £300 was for sinking. M. Morandière estimates the total cost of a cylinder sunk like those at Argenteuil, at a depth of 50 feet, at £1,440.

Considering next the cost of piers of masonry on wrought-iron caissons of excavation; the foundations of the Lorient viaduct over the Scorff cost the large sum of £4 19s. per cubic yard, owing to difficulties caused by the tides, the labor of removing the boulders from underneath the caisson, and the large cost of plant for only two piers. The foundations of the Kehl bridge cost still more, about £5 16s. per cubic yard; but this cannot be regared as a fair instance, being the first attempt of the kind.

The foundations of the Nantes bridges, sunk 56 feet below low-water level, cost about £3 1s. per cubic yard. The average cost per pier was as follows:

	£
Caisson (41 feet 4 inches by 14 feet 5 inches), 50 tons of wrought-iron at £24	1,200
Cofferdam, 3 tons of wrought-iron at £12	36
Excavation, 916 cubic yards at 18s. 4d..	840
Concrete	860
Masonry, plant, &c.	384
	£3,320

One pier of the bridge over the Meuse at Rotterdam, with a caisson of 222 tons and a cofferdam casing of 94 tons, and sunk 75 feet below high water, cost £14,550, or £2 17s. 5d. per cubic yard.

The Vichy bridge has five piers built on caissons, 34 feet by 13 feet, and the abutments on caissons 26 feet by 24 feet. The foundations were sunk 23 feet in the ground, the upper portion consisting of shingle and conglomerated gravel, and the last 10 feet of marl. The cost of the bridge was as follows:

	£
Interest for eight months and depreciation of plant worth £4,000	800
Cost of preparations, approach bridge and staging	1,007
Caissons, No. 7, 150¾ tons at £23 6s.	3,513
Sinking	2,017
Concrete and masonry	1,089
Contractor's bonus and general expenses	1,254
	£9,680

The cost per cubic yard of foundation below low water was £3 8s. 7d., of which the sinking alone cost 15s. 3d. in gravel, and 19s. in marl. At St. Maurice the cost per cubic yard of foundation was £3 5s. 6d., exclusive of staging.

The Author has treated of the subject of tubular foundations at some length,

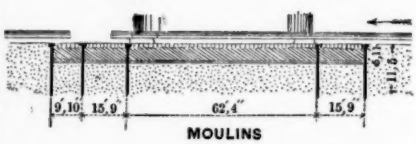
because they are the most effectual means at the disposal of engineers for carrying foundations to great depths below water. Economical considerations render it desirable to adopt pumping or dredging when possible; but compressed air is very serviceable where boulders or other obstacles are met with, or where, as at Vichy, the ground is conglomerated and unsuitable for dredging. In cases where the proper course to be adopted is a matter of doubt, the success at the Gorai bridge, and the power of resorting to the aid of divers, if necessary, would encourage an attempt being made to dispense with compressed air, which at great depths, such as 100 feet under water, is attended with danger. The Tet bridge, moreover, furnishes an example of the possibility of resorting at last to compressed air if found indispensable.

In soft ground of unknown depth the best methods for making foundations are those already described; but it is sometimes advisable in small works to adopt more economical methods. Two distinct cases have to be considered :— 1. Where the soil is firm, but liable to be scoured to great depths; 2. Where the soil is soft as well as exposed to considerable scour.

Régemortes gained a reputation by his method of dealing with an instance of the first of these two cases at Moulins, where several bridges had been destroyed one after another by scour in floods, owing to the piles on which they rested being unable to penetrate far enough into the film sand composing the bed of the Allier.

Régemortes, in 1750, renounced the idea of finding a stable foundation far down, and built on the surface, rendering it secure from scour by covering it with a masonry apron. The apron, having a uniform thickness of 6 feet (Fig. 21),

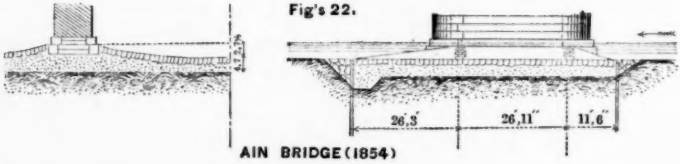
Fig. 21.



MOULINS

was laid on the dredged and levelled bed, dried by diverting the stream, or, in some places, by inclosing it with timber and pumping out the water. The infiltration through the bottom was stopped by depositing a layer of clay all over, and then lowering caulked timber panels in it. This method has, however, been much simplified by the introduction of hydraulic concrete. The apron at the West Viaduct at Amsterdam consists of a layer of concrete, 4 feet thick, placed on piling, and protected at the ends by sheeting. The apron of the Guétin canal bridge, constructed by M. Jullien in 1829, is 69 feet wide, 5 feet 5 inches thick, and 1,640 feet long. The concrete was carried down to a depth of 11½ feet at each end between two rows of sheeting 6½ feet apart. Another form of apron was adopted at the Ain bridge (Fig. 22), with a single row of sheeting

Fig's 22.



AIN BRIDGE (1854)

at each end, 26¼ feet from the facing of the bridge at the lower end, and 11½ feet at the upper end. The lower or down-stream ends of the apron were always the most secured against scour, in the belief that a cavity would be formed below by the scouring away of the sand, but that above the currents would bring down sand and fill up any hollows that might have been scoured out. The investigations however, of MM. Minard and Marchall on the floods of the Loire and the Allier in 1856 indicated that the upper end of the apron is most exposed to scour and requires most protection, as the river bed close to the lower end is protected by the apron, whereas at the upper end the river bed is exposed to the full force of the current where the obstructions of the piers produce whirl-

pools. The apron of the Ain bridge cost £7 15s. 9d. per square yard of clear roadway above, or nearly as much as the bridge which it supports.

In certain instances the movable bed of a river has been sufficiently consolidated at the site of a work by merely a thick layer of rubble stones thrown in, giving time for the stones to take their final settlement during floods. Lastly, a movable bed can be consolidated by a wooden stockade; one of these was made, in 1820, below Amboise bridge, like the one Perronet had put down under the Orleans bridge in 1761, and both have stood perfectly.

The second case of a soil both soft and liable to scour has next to be considered. Where considerations of expense forbid going down to the solid, the following methods have been adopted:

(1) The ground is sometimes consolidated by driving a number of piles close together, or by covering it with rubble stones with or without fascine-work, so as to form a kind of superficial crust capable of bearing the structure. It is, however, generally advisable to break through the superficial stratum, and to produce a compression extending down a considerable depth by a large weight of earth, as was done for the railway bridge crossing Lake Mälar at Stockholm, where there is a thickness of 69 feet of silt under 79 feet of water. A large embankment of sand was tipped in and inclosed by sheeting, within which close rows of piles were driven, and then a water-tight caisson was lowered on a platform sunk 3¼ feet below the water, in which the foundations were commenced.

(2) Another method is to increase the bearing surface at the base by large footings, or by timber platforms, layers of concrete, bedding courses of masonry, or rubble stone.

(3) The weight of the superstructure can be diminished by forming hollow cells in the masonry, or by using iron girders instead of stone arches.

(4) In heterogeneous strata the weight must be distributed as much as possible in proportion to the bearing power at different points.

(5) It is advisable sometimes to inclose the site of the foundations with sheeting, walls, &c., not only as a protection against scour, but also to prevent the running-in of the soil from the sides when a weight is brought on it.

The Cubsac suspension bridge over the Dordogne furnishes a good example of a successful surmounting of difficulties in foundations. The suspended roadway was made as light as possible; the piers were hollow and perforated cast-iron columns, resting on a stone base supported by piles from 40 to 62 feet long, and 2 feet 7½ inches apart. The abutments and anchorage masonry were built with arched openings and light inverts, and the embankments at each end were of light limestone blocks arranged in rough arches so as to form hollow spaces in the mass.

Although in this enumeration of the different kinds of foundations bridges have generally been chosen for examples, the methods described would be applicable to other works, such as large locks, graving docks, and quay walls.

The difficulties attending the laying of lighthouse foundations, and the means adopted to surmount them, are fully detailed in descriptions of these works.

In sea works the chief difficulties are encountered above the foundations where the sea breaks against the structure, and accordingly the methods of protection adopted do not come within the limits of this Paper. But the valuable addition to the methods of foundations used for these works by the introduction of concrete blocks, which can be formed of almost any size, and deposited by divers, must not be overlooked.

The effect of pumping or hammering action referred to by Mr. W. Parkes and Sir John Coode (vol. xxxvi., Minutes of Proceedings Inst. C.E., pp. 234 and 240) is due to the immersion and emersion during the oscillation of waves. Perhaps to this cause may be partially attributed the fall of a quay wall at Vevey in the present year. This wall was founded with a base of concrete contained in metallic boxes resting on high timber piles.

M. Croizette Desnoyers has framed a classification of the methods of foundations most suitable for different depths, and also an estimate of the cost of each. These estimates, however, must be considered merely approximate, as unfore-

seen circumstances produce considerable variations in works of this nature.

	Depths.	Per cubic yard. s.	s.
Foundations on piles after compression of the ground.....	20 to 33 feet....	12	to 18
	33 to 50 feet....	18	to 30
Foundations by sinking wells.....	33 to 50 feet....	30	to 37
Foundations by pumping.....	under 20 feet...	12	to 18
26 to 33 feet	favorable circumstances.	18	to 55
	unfavorable.....	61	to 73
Foundations on concrete under water.	20 to 33 ft. small amount of silt.	18	to 37
	26 to 33 ft. large amount of silt.	37	to 49
Foundations by means of compressed air under favorable circumstances...		55	to 67
Foundations by means of compressed air under unfavorable conditions.....	Lorient viaduct..	99	
	Kehl bridge.....	122	
	Argenteuil bridge	140	
	Bordeaux bridge.	165	

When the foundations consist of disconnected pillars or piles the above prices must be applied to the whole cubic content, including the intervals between the parts, but of course for an equal cost solid piers are the best.

For pilework foundations the square yard of base is probably a better unit than the cubic yard. Thus the foundations of the Vernon bridge, with piles from 24 to 31 feet long, and with cross timbering, concrete, and caisson, cost £14 7s. 7d. per square yard of base. According to estimates made by M. Picquenot, if the foundations had been put in by means of compressed air the cost would have been £32 15s. 7d.; with a caission, not watertight, sunk down, £13 12s. 2d.; with concrete poured into a space inclosed with sheeting, £12 15s. 7d.; and by pumping £17 3s. 2d. per square yard of base.

M. Desnoyers gives the following recommendations with regard to the choice of methods:

(1) In still water to construct the foundations by means of pumping for depths under 20 feet. In greater depths to construct ordinary works on piles if the ground is firm or has been consolidated by loading it with earth; otherwise to employ pumping, and if a permeable stratum is met with to build on it with a broad base. For important works, if the soil is watertight, it is advisable to adopt the method of pumping inside a framing, carrying down the foundations to greater depths than 33 feet by the well-sinking method. If the soil, however, is permeable, dredging and concrete deposited under water must be resorted to; compressed air being employed for depths greater than 33 feet.

(2) In mid-stream compressed air must be resorted to for foundations more than 33 feet below water. In less depths the foundations of ordinary works are put in by means of dams or watertight frames if the nature of the silt admits of pumping out the water; but if the silt is permeable a mass of concrete is poured into the site inclosed by sheeting. When, however, an important work has to be executed, it is desirable to use pumps sufficient to overcome the infiltrations. If a permeable and easily-dredged stratum lies between the hard bottom and the silt the method of a watertight casing, with a dam at the bottom, should be adopted. To complete these recommendations open cylindrical foundations must be included. These may be resorted to, instead of compressed air, when the soil is readily dredged or watertight enough to allow of pumping, and also frequently in the place of piles or the well-sinking method. The compressed air system is essentially a last resource, applicable to a bed exposed to scour, and also either difficult to dredge or with boulders or other obstacles imbedded in it.

In conclusion, a chronological list of works is added to show at what periods the principal steps in advance were made.

The system of rubble mounds is the most ancient; and dams of earth came into vogue in the seventeenth century. In 1500–1507, the "Notre Dame" bridge at Paris was founded on piles surrounded with heavy rubble stones. In 1716 the Blois bridge was built on piles and a platform at low-water level. The method of constructing a foundation by means of an apron was introduced by Régemortes at Moulins in 1750. At the same time Labelye built the foundations of the old Westminster bridge by sinking caissons in the dredged bed of the Thames, a similar process having been adopted, in 1686, for the pier of the Tuileries bridge next the right bank of the Seine. In 1756 Des Essarts invented

a saw for cutting off piles under water, which enabled a caisson to be deposited on piles for the Saumur bridge, a method thenceforward adopted for the bridges at Paris till 1857, also for the Sévres, Ivry, and Bordeaux bridges, and old Blackfriars bridge was built in the same way.

In the year 1818 Vicat discovered the properties of hydraulic mortars, and the adoption of a concrete foundation deposited inside sheeting soon followed; also the bottomless frame system with concrete at the bottom, first used by Beaudemoulin for several bridges at Paris, and adopted for the bridge over the Cher.

In 1833–40 Poirel employed for the first time artificial blocks of concrete at Algiers harbor. He also used caissons with a bottom of canvas for depositing liquid concrete *in situ*.

M. Triger first used compressed air at the Chalons coal mine in 1839; and Dr. Potts introduced his system in 1845.

The tubular method of foundations was next introduced, and under various forms is continually becoming more universally adopted. The following are the dates of some of the works for which it was used:—

Gravesend cofferdam. Mr. J. B. Redman	1842
Rochester bridge. Mr. Cubitt	1851
Saltash bridge. Mr. I. K. Brunel	1854–57
Kehl bridge. Messrs. Fleur St. Denis and Vuigner	1858–59
Charing Cross bridge. Sir J. Hawkshaw	1860
Cannon Street bridge. Sir J. Hawkshaw	1863
Victoria bridge. Sir Charles Fox	1863

In 1867 Kennard's sand-pump was used for the foundations of the Jumna bridge.

The "boring-head" was used by Mr. Leslie in 1867–70 at the Gorai bridge, and at the same time Mr. Milroy introduced his "excavator."

Lastly, between 1870 and 1873 the Americans laid the foundations of the St. Louis and East River bridges, whilst Mr. Stoney, by depositing huge blocks in the Liffey, and Mr. Dyce Cay, by depositing concrete *in situ* in large masses at the Aberdeen break-water, extended the methods of employing concrete in river and sea works.

PROGRESS OF THE SLAG INDUSTRIES DURING THE LAST FOUR YEARS.*

By Mr. CHARLES WOOD.

From "Journal of the Society of Arts."

It is now four years since I had the honor to read before you a short paper upon the "Utilization of Blast Furnace Slag."

I am not aware that at that time (with the exception of the use of slag for road metal) there was a single instance in this country of slag being successfully manufactured into a commercial commodity, although, as I have mentioned in a paper read before another society, nearly 60 different systems had been patented or tried, resulting only, in many cases, in disappointment, after enormous expenditure of both time and money.

At the present moment I can point out nearly a dozen different classes of goods into which slag is being manufactured, whilst the different uses to which some of these products are being applied are very various, and are daily on the increase. I have, at the end of this paper, appended a small list, showing a few of the forms into which blast furnace slag is being made, and to what purposes it is being applied.

In my former paper I showed you how the slag properly prepared might be employed, but I had nothing to confirm what I there stated. I will now try to prove that all I then suggested has been fully realised, and I will show that the manufacture of slag into mortar, cement, building bricks, and a superior concrete (which will set perfectly in water) is now being carried on at Middlesbrough,

* Paper read before the Iron and Steel Institute at Newcastle.

and, even in these bad times, at a reasonable profit.

In the first place, I may mention that, at the Tees Iron Works, there are three slag sand machines and two slag shingle machines working, and these machines have produced not far short of 100,000 tons, all of which has been utilized in a profitable manner.

In order thoroughly to test the value of slag made by my two machines for the various purposes just mentioned, it was thought advisable to form a company that should take up the manufacture as a specialty, and who could devote the time and attention so necessary to a young and untried industry. This company has now been in operation about two years and a half, and, like most new concerns when attempting the manufacture of a fresh material, it has had to pass through a severe ordeal. The difficulties met with have been numerous. The failure of one machine after another, the loss of time, patience, and money, would have ruined many private individuals, but thanks to Messrs. Gilkes, Wilson, Pease, and Co., and to a few friends in the Slag Company, I have been enabled to pass through the ordeal, and I am thankful to say that neither their confidence, money, nor time is likely to be lost; but that there is every probability that, with a larger output and a revival of trade, their capital will receive a fair dividend.

The Cleveland Slag Company's works are situated near the docks at Middlesbrough, and are now paying between £60 and £70 per week in wages. The most important part of their manufacture is slag bricks for building purposes, made from the slag sand, produced by the slag sand machines at the blast furnaces. This sand is mixed with selenitic lime (General Scott's patent), with an addition of iron oxide, and is pressed in a machine hereafter to be described.

The next article of importance manufactured at these works is a kind of hydraulic cement, made from the slag sand, common lime, and iron oxides. Compared with Portland cement for hydraulic work or concrete, this is the most valuable product introduced for many years, whilst its price is not one-fourth, and the strength little inferior.

Concrete made from this cement, mixed with the shingle produced from the rotary table, is an excellent conglomerate for use in monolithic structures. With this material I have executed some very heavy blast engine foundations—in one case where brickwork set in cement had previously failed. The concrete is now standing in the most perfect manner. The cost of the concrete is only about one-fourth that of the brickwork, and experience has shown that it goes on hardening for months. The building of the Slag Company's works is executed entirely in this material—the walls being nearly 80 feet high—they were built entirely by laborers, without a single bricklayer, and the cost of the work when finished, including superintendence, did not exceed six shillings per cubic yard. To give an idea of the strength of the walls, I may mention that on one or two occasions we have had to cut doorways through them, and it has taken two good men with steel bars and sledge hammers as much as four days to cut through a thickness of about twenty-six inches.

Mortar is also made and sold in large quantities from a mixture of slag sand, and about 10 per cent. of common slaked lime, and it can be sold at the cheap rate of about 4s. per ton.

The introduction of these various products from slag at first met with a good deal of opposition and prejudice from architects and builders, but the remarkable strength and cheapness of the material soon compelled these gentlemen to admit their error, and I am happy to say that our demand in some instances is now more than the production.

As before stated, the most important branch of the business carried on by the Cleveland Slag Company is the manufacture of building bricks, and, although the process is now very simple, it has been here that the greatest difficulties have occurred. There was no machine made in England that could work the material in the state in which it is produced at the furnaces, without previous preparation; and to prepare the material to suit the brick press meant that the cost of the bricks became so high as to exclude them from the market. A press had, therefore, to be designed that would work the slag sand just as it comes from the slag sand machines directly into

bricks, and this being accomplished, success was assured.

In designing this machine, the following points had to be kept in view, viz., great depth of moulds, because the slag sand is very spongy and compressible; an arrangement by which the water could escape from the moulds without blowing the bricks to pieces; great pressure, in order to consolidate the sand in the mould; safety against over pressure, in case too much or too hard a material should get into the moulds; and great care in mixing the lime with the slag sand in fixed proportions, as well as great regularity in filling the moulds.

These requirements are fully met by the brick press which I shall now describe, and which is, in my opinion, one of the safest and most powerful mechanical brick presses ever made. The pressure is given by two cast steel cams, which are fixed upon a forged steel shaft 7½ inches in diameter. This shaft, resting on bearings between two strong frames, is put in motion by very powerful double-geared spur wheels, the first motion shaft having a fly-wheel upon it to steady and equalize the pull upon the strap. The pressure cams act against rollers fixed upon two steel cylinders or rams. These rams transmit the pressure to the moulds in a table. The table is circular, and contains six pairs of moulds, so that four bricks are pressed at one time, the table remaining stationary during the operation. At the same time the bricks are being pressed, two other pairs of moulds are being filled up with material—whilst the other two pairs are delivering up the four bricks pressed at the previous revolution of the cam shaft. The bricks are pushed out of the mould by smaller pistons acted upon by separate cams.

The moulds are lined with changeable steel plates $\frac{3}{16}$ inch thick, and the sand and lime is fed into them by two pug mills. These pug mills are fitted with six knives each, so as the more thoroughly to mix and chop the spongy slag along with the lime. The table is shifted round by a kind of ratchet motion, also worked by a cam on the outside of the framework, and acting upon the weight bar and levers.

Immediately above the pressure cylinders are two pressure stops, which are held down by the heavy-weighted levers. These levers, therefore, receive the whole pressure put upon the bricks, and in case there should be too much sand getting into the moulds they simply lift up and relieve the strain. The weights can be weighed at option, and thus form an exact gauge of the pressure upon the bricks. The moulds are generally filled so as just to lift the levers in ordinary work. The filling is easily regulated by the set of the knives on the pug shafts, which press the material into the moulds, and one side of the pug mill cylinder is made to open so that the knives are accessible at any moment.

The pug mills are filled by means of the measuring and mixing apparatus placed on the floor immediately above the brick press.

The mixing and measuring apparatus is very simple and efficient, and works without any trouble. The slag sand is tipped into a hopper by large barrows, which are lifted up by a hoist. At the bottom of this hopper there is a revolving cylinder, with ribs cast upon it, which, revolving under the hopper, carries a certain thickness of sand, the thickness having been previously regulated to the requirements of the press.

The slag then falls upon a sieve, which separates any large pieces of slag in a solid state, and at the same time allows the falling sand through the sieve to fall like a shower. The lime is fed into a separate hopper, and is regulated very much like the feed of corn into millstones. The lime then passes down a shoot, which forms part of the slag sand sieve, where it meets the shower of sand —falling together with it—thus getting thoroughly mixed. As before stated, this lime is selenitic lime, and is prepared upon the works.

The bricks, when taken from the brick press, are placed upon spring barrows, holding fifty each. They are then taken and stacked in sheds, where they are allowed to remain about five or six days, after which they are simply stacked outside in the weather to harden. The percentage of loss is very little, not amounting to two or three per cent. In fact, when once the bricks are upon the barrows, there is little or no waste.

Each machine is capable of turning out about 10,000 bricks per day, and,

since starting, we have sold about 4,000,000. Large quantities are shipped to London at a cost of 17s. to 18s. per 1,000 for freight; in other words, about 10,000 tons of slag sand has been consumed for this purpose alone. The following are a few of the advantages of these concrete slag sand bricks, viz.:—Being pressed, they are perfectly uniform in size and thickness; they are much cheaper than ordinary red bricks, compared in weight with which they will weigh one ton per thousand less, then there is this further advantage that there are no wasters or halves. For inside work there is a great saving both in bricklaying and mortar, more especially when plastering; the walls being of a uniform thickness; and the bricklayers like them, because they can do more work with less labor, the bricklayer's laborer finding he has a ton per thousand less to carry, as well as considerably less mortar. Another remarkable property of the slag bricks is that the joiners can drive nails directly into them without splitting, and thus, for skirting and door-work, they are saved much trouble in plugging the walls; and, finally, the longer the bricks are kept the harder they get.

I can now confidently say that for many months past we have been steadily working away at the various products mentioned in this paper, and that with the exception of a little outlay for the purpose of increasing our output, we have laid out no money upon experiments or works.

The task, however, has been a severe one. When I designed the mill, I brought to my assistance some of the most experienced millwrights in England —men accustomed to machinery for manipulating hard and gritty substances; and yet there is scarcely a piece of machinery on the works, with the exception of the engine and shafting, that has not either been abandoned, redesigned, or rebuilt, in order to adapt the machines to this peculiar material, the extraordinary cutting nature of which seems to destroy everything with which it came into contact. In proof of this, I may mention two facts, viz., that in six hours' working, the fields and furrows in a pair of French burr millstones, intended for Portland cement grinding, were completely obliterated, whilst the hardest steel bars in a Carr's disintegrator were cut completely through after six or eight days constant running.

The position of an engineer and an inventor under these circumstances—standing as he does between failing machinery and the angry directors of a limited company, in times like these—is one which has only to be experienced to be thoroughly appreciated; but, thanks to Messrs. Gilkes, Wilson, Peace, & Co., and to one or two practical men among the directors, I have been enabled, through their aid and confidence, to carry the thing to a successful issue.

In addition to the works and progress made by myself at the Tees Iron Works and the Cleveland Slag Working Company's Works, I must not forget the labor and success obtained by my friend Mr. Henry Hobson, engineer at the Moss Bay Iron Works, Cumberland. Mr. Hobson has taken a path different, as far as I know, to any of his predecessors, inasmuch as in making bricks he first of all pulverises the solid slag, and uses no lime whatever. By this system the slag is taken from the solid slag balls, made from hematite Bessemer iron, and broken into pieces sufficiently small to pass under very massive edge runners, where it is ground or crushed by the sheer weight of the runners into small dusty shingle. It is then passed by elevators into French burr millstones, and ground into powder.

From the stones it passes directly into the brick press without any admixture of lime or any other aid except that of being well damped with water before pressing. This brick press also has a rotary table, and the material is fed into the moulds recessed therein by hand. The pressure given from above by a self-acting cam, put in action by the continuous rotary motion of the table, the bricks come out well pressed and are of excellent shape, and there appears to be no doubt about the quality. At the same time, they have a great many wasters. The bricks are very heavy, and the cost of grinding the slag entails a heavy and expressive plant, with, I fear, a large amount of wear and tear. The large amount of lime in the slag made while producing Bessemer iron seems to be sufficient, when treated in this way, to

reunite the pulverized slag and to "set" in a most remarkable manner. I can only account for this setting property by supposing that the slag, when pulverized in the dry state in which it comes from the furnace, takes up a large amount of water, and forms a hydrated compound of silicate of lime and alumina, and thus reunites the mass in the same way as Portland or Roman cement.* On the other hand, this excess of lime is often very dangerous, as the slag, after exposure to the air or an excess of moisture, often swells and falls into powder, and bricks made from it are liable to fall to pieces. This, however, is not the case with Cleveland slag, nor, I think, with any except with that made from hematite ore with an excess of lime.

The next process in successful operation is that known as Woodward's, and, although a revival of a very old method, I must certainly give that gentleman, and those who have worked the thing out at the furnaces, a great deal of credit for their perseverance, and for the success at which they have arrived. I must also, in all honesty to them, say that most of their manufactured articles are of a very serviceable nature. They are, however, employed for footpaths, roads, &c., being totally unfit for building puroses. As at present worked, the process is not at all complicated, but only certain qualities of slag are suitable, and at times when the furnaces are "changing" the number of wasters is enormous, while the works have sometimes to be stopped for days. The slag is run direct from the furnaces into moulds ranged round the outside of a large rotary table. The machine or table remains stationary whilst each separate mould is being filled, the table is moved by hand, thus constantly presenting empty moulds to the stream of molten slag. As soon as the slag becomes set in the moulds a catch is knocked away, and the bottom of the mould drops down upon a hinge and the brick or block falls out. It is then taken into annealing ovens, where the temperature is raised to nearly a white heat, after which it is allowed to cool. The high price obtained in the market for these goods enables the company to meet their expenses, but, I believe up to the present time they have not done more than this. The goods they produce are very hard, uniform in size, and look well when laid; but they are liable to crack, particularly in winter, and, as before mentioned, there are many objections to their ever being employed as building material.

At the Leeds meeting of this institute last year, Mr. Bashley Britten introduced to your notice his novel system of making glass from blast furnace slag. Mr. Britten, it will be remembered, proposed to take the molten slag in a ladle from the blast furnace and to pour it into a Siemens furnace, where certain additions of carbonate of soda and silica are added according to the quality of the slag used and the glass to be produced.

I am very glad to learn from Mr. Britten that the extensive experiments which have been carried on during the year have proved perfectly successful, and that, under the title of "Britten's Patent Glass Company," for which Mr. Herbert Canning is the secretary, large works are being built at Finedon, in Northamptonshire, where in a few months they will be ready to manufacture large quantities of glass bottles. These bottles on the tables are made entirely by this process.

I have now only one more product from slag to mention. It is that of slag wool, or, as it is sometimes called silicate cotton, from its great resemblace to cotton wool. The manufacture of slag wool hasoften been attempted in England, but I believe only with partial success.

I have, however, learned from Mr. Edward Williams that many years ago Mr. Edward Parry made a large quantity of it in Wales, although that, in consequence of the injurious effect upon the men, it had to be abandoned. The manufacture is now carried on at the Tees Iron Works, and I can safely assert, without the slightest inconvenience, either to the men in the yard, or even to the man who makes it.

The process is extremely simple. A jet of steam is made to strike upon the stream of molten slag as it falls from the usual runner into the slag bogies or waggons. This jet scatters the molten slag into shot, and as each shot leaves the stream it carries a fine thread or tail with it; the shot, being heavy, drops into the ground, whilst the fine woolly fibre is

* I have given an analysis of an average sample of Bessemer and Cleveland slag at the end of my paper for reference.

sucked into a large tube and discharged into a chamber. This chamber is very large, and is covered with fine wire netting or sieve wire. The steam and air carry the woolly particles all over the chamber—the finest into recesses formed for the purpose; the heavier into the body of the chamber. After each blowing it is selected and taken up with forks and put into large casks or bags for shipment or otherwise. The inside of the chamber represents a most remarkable and curious spectacle after each blowing.

The wool, as will be seen by the samples on the table, is of a snowy-white appearance. Slag wool, or silicate cotton, is chiefly employed to cover steam boilers, pipes, &c. Messrs. Jones, Dade & Co., of London, are the sole agents for its sale, and they have taken out one or two patents for its application. The most noteworthy of these is for what they term mattresses, some of which they have kindly forwarded for inspection. These are about 2 ft. to 3 ft. long, and 1 ft. wide, by 2½ in. thick. The mattresses are laid upon the boiler or pipes to be covered, and are secured in the usual way. Its perfect incombustibility, combined with its non-conducting and indestructible properties, give this material many advantages over any other for this class of work.

Table showing the various Forms into which Blast Furnace Slag is being made, and to what Purpose it is being Applied.

Slag Sand.—This is employed for making concrete, building bricks, mortar, and cement; for agricultural purposes and gardening.

Slag Shingle is being used largely for concrete, and for roads and footpaths.

Slag Wool.—For covering steam boilers, steam pipes, hot-water pipes, fire-proof rooms, ice-houses, cisterns, gas and water pipes, as a protection against fire, as well as for filtering chemicals.

Paving Blocks.—Employed for streets and footpaths, stables, coach-house yards, crossings, breweries, and for kerbstones and channelling.

Building Bricks.—Made by pulverizing the solid slag and then pressing the bricks in a press.

Glass, by Mr. Bashley Britten's patent process, into roofing glass, bottles, guage glasses, and many other articles too numerous to mention, for which a pure glass is not absolutely essential.

Analysis of Blast Furnace Slag.

	Cleveland. Per cent.		Bessemer. Per cent.
Silica	36.50	..	35.00
Alumina	22.95	..	15.00
Lime	32.68	..	46.40
Magnesia	5.83	..	2.00
Protoxide of iron	0.06	..	0.10
" manganese	0.32	..	0.10
Potash	0.59	..	0.40
Soda	0.37	..	0.20
Sulphur	1.74	..	1.50
Phosphoric acid	*nil.*	..	*nil.*
	101.04	..	100.70
Less ogygen of sulphur.	0.87	..	0.75
Total	100.17	..	99.95

ON SCIENTIFIC METHOD.

By M. M. PATTISON MUIR, F.R.S.E.

From "The Quarterly Journal of Science."

WHETHER we turn our attention on ourselves, or seek to pursue the study of mankind in general, or, on the other hand, confine our view to the natural world around us, there is in each case one method by pursuing which we arrive at exact knowledge: that method is the Scientific. What, then, is Science, and what the scientific method? The question, What is Science? is synonymous with another, What is Knowledge? Here is a stone: how do I know it to be a stone? Because it is *like* so many other things which I call stones; it is hard, it possesses a certain color, it is not easily broken, and so on. I know that it is a stone because I recognise in it certain qualities which I have grouped together and regarded as characteristic of those pieces of matter, to all of which

I therefore apply one general name, viz., *stone*. In stones, therefore, there is some quality, or qualities, possessed by all in common, such qualities being sufficient to mark off the possessors of them from all other kinds of matter. Yet these stones may differ from one another in many other ways.

Such a classification is a scientific one. I *know* something about these stones. Were there only one piece of stone in the world I could never know anything about it as a stone. To know we must compare; and the scientific method consists in finding unity amid variety, in tracing the inner relationships between seemingly diverse things (or thoughts), in finding the common link which binds together those things at first sight appearing so widely separated.

This, then, is the aim of Science—to know. And to attain this aim she must find the agreements and differences between all things; in other words, she must classify. When we have arrived at a complete system of classification of all phenomena we shall have attained the purely scientific aim of our intellectual existence.

To awaken consciousness there must be more than one phenomenon. Object is compared and contrasted with object, and hereby resemblances and differences are discovered: these are retained in the memory, and compared with other resemblances and differences, as these may be discovered, until at last we are able to find identity amid diversity, to group together a number of objects by means of some great common property, and from this identity to draw inferences which rest on some point of resemblance, and which have for their basis the law that "that which is true of one thing is true of its equivalent." We gradually leave behind us the old idea that ceaseless change is the order of all things; we learn to believe that what we to-day know as Iron will yet be Iron a thousand years hence; we get something definite to reason on, and, step by step, the varied and strange phenomena of Nature are found to be lawful phenomena—are found to have a fixed basis underlying them; until at last we arrive at a general expression for so many and so varied phenomena that we give it the name of a *law of Nature*. Thus we rise from the trivial to the abiding, from the changing to the changeless, from the passing to that which endures, and from that which was capricious to that which is governed by law.

But even here, even in these *natural laws* we have not attained absolute certainty; they are but general expressions, including a vast number of else isolated phenomena. But what is beyond these phenomena? What is the cause of all these causes? Science, strictly so-called, gives no reply.

It may be urged that modern science teaches that all things are in a continual state of change; that there is no such thing as rest in the physical universe; that every form of energy is but the expression of a change of material particles: but Science, we answer, has gained this knowledge only by grasping the changeless facts underlying the changing phenomena. We do not now simply know that the material universe is constantly undergoing change: we are able, to some extent, to follow the steps of this change; we have reduced the very mutability of Nature to law; we have compared change with change, and in some instances have succeeded in detecting the connecting-link. We have made a beginning in the classification of the changes of Nature.

If the aim of Science be to detect identity amid variety, it is asked—What means does she employ for accomplishing this end? *Observation, Experiment, and Inference.*

From repeated observations we discover an identity; from a number of identities we infer that what is true of one is true of another; from a number of combined inferences we draw a wider inference, which again we generalize into what is called a law. But before we can establish a law we must make use of the process of deduction—if such or such an inference be true, then this or that phenomenon must follow. Observation or experiment tells us whether the phenomenon does occur or not; if it does, another proof of the correctness of the law is gained; if it does not, there is the less probability that the so-called law is a true one. Thus it is from a series of partial hypotheses which generalize a number of facts that we at last ascend to *the* hypothesis which shall in-

clude in its expression all the isolated facts—that is, to a general law. And this method of combined observation, experiment, induction, and deduction is the Scientific Method.

There is nothing peculiar in this method; it is but common sense reduced to rule. We are continually and unconsciously guided by the scientific method in our every-day conduct. The countryman who, in the morning, assures his neighbor that it will rain before midday, bases his assurance upon a train of scientific reasoning; he has repeatedly observed that certain appearances of sky, a certain direction of wind, and rain, are associated together: from these observations he has, probably unconsciously, framed the hypothesis that the three sets of phenomena are related together in such a manner that, given the two first, the third is sure to follow; he has proved the value of his hypothesis again and again, by acting on it,—the only scientific method of proving an hypothesis,—and he at last has come to regard it as a law of Nature. But after all it is only an hypothesis, probably a very partial one, and Nature will very likely some day teach him that he has been too ready to narrow her working to the sphere of his own capacities.

The scientific method is applicable, more or less, to all branches of phenomena coming within the scope of human understanding. But the domain claimed by Science is so great as to make it impossible for any man, or body of men, to examine it with completeness. Hence arises the necessity for divisions and subdivisions in Science. The first part which must be examined is, clearly, the laws which regulate reason itself, the laws of thought, and their application to the processes of inference. The study of these belongs to the Science of Logic. The application of these principles to reasoning about numbers and quantities constitutes the Science of Mathematics, and so on.

We have one set of sciences dealing with physical or material objects; another with mental, moral, or immaterial objects; or with these as they are modified by social relationships. Hence arise the two broad classes of natural or material, and mental or moral science. The scientific method is applicable to both alike, only the questions arising under the second division are more complicated and much more difficult of solution than those under the first. Indeed it is only within recent years that the scientific method has been, in any great degree, applied to the questions of mental and social phenomena.

In endeavoring to classify scientifically the phenomena of Nature we make use of the method, first of all, of Observation.

From experience we gather together a number of facts, but in order to classify these facts we need often have recourse to Experiment.

In the first-named process we do not alter the conditions under which phenomena occur in Nature; we *merely observe* these phenomena as they are presented to us, or at most we *vary our point of view*. In carrying out an experiment, on the other hand, we must carefully vary the *conditions of the phenomenon*, and endeavor, as far as possible, to exclude those which have no influence upon the fact we are studying.

Observation and experiment are the first steps in the ladder leading upward to scientific knowledge.

But where are observations to begin? In our world facts are so numerous, phenomena so almost infinite in number, that no man can say which are to be observed and which neglected. Hence we find that many of the greatest scientific discoveries have taken their rise from what we call "chance" observations. But that which is passed by, by one man, as altogether unimportant, in the hands of another leads to the most important results. The twitching of the leg of a dead frog when accidentally touched by the wires coming from a battery caught the eye of Galvani, and he, following up this chance observation, so added new facts and new theories to our scientific stock that one of the greatest branches of Electric Science now derives its name from this man.

It is impossible, however, to carry out the method of observation beyond certain limits. Our powers of hearing are not delicate enough to perceive vibrations exceeding somewhere about 38,000 per second; hence if there be sound-producing vibrations quicker than these no amount of observation will enable us to

detect them. Not only is this method unable to pass beyond somewhat narrow limits,—it is also liable to lead us to untrue conclusions, unless it be very carefully used. Do we not often hear it said—"See how the buildings of our great ancestors have lasted during the centuries,—strong and firm these old temples, or walls, or roads remain to this day, while the structure which we have raised to-day by to-morrow begins to decay?" Observation tells us that the older buildings remain; observation tells us that the newer quickly disappear; but observation does not tell us that it is only the great buildings of antiquity which remain—the buildings which, from their purpose and design, we should expect to be *very* strongly put together; and that the ordinary houses and the common buildings have all *long ago* utterly disappeared. The conclusion drawn from observation alone—viz., that our ancestors built more strongly than we do—is therefore a conclusion which is not proved by the evidence adduced.

Again, the mind of the observer may be so overcast with prejudice or fancy, or may be so dim and dull as either not to receive aright the image of outward things, or to transpose that image so that it becomes a caricature, not a truthful picture. He who when shown, in the old heathen temple, the picture of all those who had been saved from shipwreck after paying their vows, and asked to believe *now* in the power of the gods, replied "But where are they who paid their vows and were not saved from shipwreck?" was a man whom we have often need to copy.

By *observation alone* we cannot tell the *exact* conditions regulating the occurrence of any phenomena; these conditions can be determined only by *experiment*. But where an observation has been made, and we are wishful to determine the exact conditions which regulate the occurrence of the observed fact, we shall find that it is very difficult to fix on these conditions. Every fact is so closely related to so many others that it becomes very hard to strike out those conditions which are really non-essential. Nay, it often happens that what at first sight appears to be the most important condition of a phenomenon proves, after experiment, to have little or no influence on this phenomenon while other overlooked circumstances are the true governing causes. Thus if we let fall a piece of lead and a sheet of paper of the same weight, from a height, we find that the lead reaches the ground long before the paper does. We should naturally conclude—as all, or almost all men did before the time of Galileo—that the *nature* of the two bodies influences the velocity of their descent; whereas it is actually found, by carefully conducted experiments, that no property of bodies except their absolute mass has any influence upon their gravitating powers. In experiment we must therefore seek to eliminate, one by one, those circumstances which are really not of importance as influencing the phenomenon in question; we must simplify the experiment as far as possible, taking care, however, that in our attempts at simplification we do not overlook *the* circumstance really governing the phenomenon. After all, however, some overlooked condition may be present, the non-observance of which entirely vitiates our results. Experiments were long ago very carefully carried out with a view to prove that earth can be formed from water; water was again and again distilled from a perfectly clean glass vessel, yet there remained a small quantity of a white earth in the vessel in which the water was distilled. If the water has not been converted into the white earth, where has this substance come from? The conclusion seemed inevitable, and the conclusion was therefore adopted—water may be converted into earth. But the overlooked circumstance was this:—Water acts on glass, especially at high temperatures, so as to dissolve part of it, and the white earth is really a portion of the glass vessel dissolved by the boiling water, and left in the vessel when the water has been entirely boiled away.

An exceedingly instructive example of the process of elimination of non-important conditions of experiment is afforded by Sir Humphrey Davy's researches upon the electrolysis of water. When water was decomposed by the electric current, an acid and an alkali invariably made their appearance at the poles along with the oxygen and hydrogen. Electricity, some people supposed,

caused the production of the acid and the alkali; others imagined that water always contains acid and alkali. By using agate or gold vessels in place of glass, to contain the water, Davy showed that less acid and less alkali was produced. Finally, by carrying out the decomposition in gold vessels, in the exhausted bell-jar of an air-pump, he was able to obtain from pure water, oxygen and hydrogen free from both acid and alkali, thus showing that the presence of air was in some way the cause of the production of the acid and of the alkali.

If, therefore, an experiment seems to point irresistibly to this or that conclusion, we must be very chary in accepting this result until we have again and again varied the conditions of the experiment, so as to bring under notice every circumstance which can in any way influence the phenomenon we are investigating.

To discover what condition may or may not influence a given phenomenon becomes therefore one of the most important problems of the scientific investigator. And here the man of a keen insight and quick apprehension has a very great—in fact, an immeasurable—advantage over the ordinary dull and plodding experimenter.

There seems to be a somewhat widespread idea that there is no longer any use for genius; that magnificent laboratories, elaborate organization, Government endowment, and certificated teachers are to carry all before them, and achieve results such as the world has never seen. To me it seems that now, as ever, genius is necessary for any really great discoveries; that no amount of training, nor of organisation, nor of artificial selection, can make up for the absence of native talent—of that subtle, scarce definable something, which we call genius.

If the genius is there, by all means let us educate it as best we may; let us also do our utmost to train all, whether possessed of genius or not,—for in doing this we shall, at any rate, be giving to all the means of leading a nobler and a more useful life than they otherwise could; but let us beware of thinking that *we* can evoke this rare and wonderful product, genius, by any method of selection, or by any system of competitive examination: plodding, persevering, patient work is of the very utmost importance; but the power of grasping the one true condition of a problem, to the exclusion of the many trivial but *seemingly* important conditions, is of yet more importance; while he who combines both of these qualities,—he who has genius to see and patience to follow,—he it is who stands forth as the great discoverer, as the poet of Science. The successful investigator of Nature must be patient; he must very often reserve his judgment until experiment proves to him that this or that conclusion must be the right one; he must be ready to frame hypotheses, but he must not shrink from submitting these to the most rigorous experimental test, and when he finds experiment and hypothesis opposed he must be ready to doubt the latter, but yet not despair of finding another truer generalization; he must never disdain help, even from the humblest; he must have no envy; he must neglect no objection; he must not choose and *then* compare, but after comparing many times he must choose; and while he is thus humble he must not hesitate to frame hypotheses,—he must risk something in his search for truth, knowing that in rigorous experiment he has a means of trying his queries whether they be true or not. "The philosopher," says Faraday, "should be a man willing to listen to every suggestion, but determined to judge for himself. He should not be biassed by appearances; have no favorite hypothesis; be of no school; and in doctrine have no master. He should not be a respecter of persons, but of things. Truth should be his primary object. If to these qualities be added industry, he may indeed hope to walk within the veil of the temple of Nature.

I have said that we still need men of genius who can see through the tangled web of facts and catch a glimpse of the governing power behind. But it may be asked, Is not this a different method from that of strictly inductive reasoning recommended by the great father of true logic, Bacon himself? Yes, it is somewhat different; yet I think that a due attention to historical facts will show us that without deductive reasoning no true generalizations have ever been reached in Science.

By an examination of facts alone we

gain empirical knowledge; scientific unity can only be gained by embracing these facts within one general principle. A mere collection of empirical facts does not constitute scientific knowledge; we must explain these facts,—that is, we must take out the folds, "*Ex plicis plana redere*," we must show the resemblances, more or less deep, between the facts; so long as a fact remains alone, unattached and seemingly unattachable to any other, we feel a certain uneasiness, unsatisfiedness, in regarding this fact; and such an uneasiness *may have*—in certain ages *has*—developed into a superstitious dread of the unexplained fact. In other ages than the present the sweep of the comet across the sky was regarded as an omen of evil,—it was an awful unexplained fact,—but now that we know that the laws governing the movements of the comets are the same as those which rule the calm and peaceful stars, we no longer experience any dread at the approach of these, once fearful, visitors. But the man of Science is often taunted with his lack of awe and reverence of the mysteries of Nature: the accusation is, I believe, only made—if made in earnest—by those who cannot take the trouble of investigating Nature for themselves; by those who think it a grander thing to speak of mystery, and greatness, and reverence, than to exhibit those qualities in themselves which they demand in others. To quote the words of Charles Kingsley:—"There is a scientific reverence, a reverence of courage, which is surely one of the highest forms of reverence, that, namely, which so reveres every fact that it dare not overlook or falsify it, seem it never so minute; which feels that because it is a fact it cannot be minute, cannot be unimportant; . . . . . and which, therefore, just because it stands in solemn awe of such paltry facts as the Scolopax feather in a snipe's pinion, or the jagged leaves which appear capriciously in certain honeysuckles, believes that there is likely to be some deep and wide secret underlying them which is worth years of thought to solve. But as for that other reverence which shuts its eyes and ears in pious awe . . . what is it but cowardice, very pitiable when unmasked; and what is its child but ignorance, as pitiable, which would be ludicrous were it not so injurious?"

To return to the main subject. We wish for hypotheses which shall explain our observed or experimentally determined facts. If we are determined to do without hypotheses in our scientific method, let us see what is required of us. Given two circumstances, and one hundred other distinct circumstances which may possibly be connected with these, we are required to find, by mere inductive reasoning, the law regulating the coincidences existing between these circumstances. Now there are no less than 4950 pairs of circumstances, under the conditions just named, between which a coincidence may exist. We shall therefore be required to try these 4950 cases, in order to determine which of them represents the true grouping of the connected circumstances. Would it not be easier, after attentively looking at all the circumstances, to say, probably the coincidence lies here, and then try whether it does or not?

As an illustration of the vast number of combinations possible under certain circumstances the following is instructive:—In whist, four hands of thirteen cards each are simultaneously held: "The number of distinct possible deals is so great that twenty-eight figures are required to express them. If the whole population of the world—say a hundred thousand million persons—were to deal cards day and night for one hundred million years, they would not have exhausted in this time one one-hundred-thousandth part of the possible deals." If we do not know anything of hypotheses, do not hazard at the least a guess, we shall very probably find ourselves—like the alchemists—spending our years in useful labor, searching in the labyrinth of detached facts without any guide, and, like them, we shall arrive at no true results.

The doctrine or theory of combinations enables us to determine the possible number of ways in which a given set of facts or circumstances may be grouped together. This theory is of the utmost importance in enabling us to form just conceptions of the nature of the task set before him who would investigate Nature. The importance of the doctrine of combinations is thus insisted on by James Bernouilli:—"It is easy to perceive that the prodigious variety which

appears both in the works of Nature and in the actions of man, and which constitutes the greatest part of the beauty of the Universe, is owing to the multitude of different ways in which its several parts are mixed with, or placed near, each other. But because the number of causes that concur in producing a given event, or effect, is oftentimes so immensely great, and the causes themselves are so different one from another, that it is extremely difficult to reckon up all the different ways in which they may be arranged or combined together. It often happens that men, even of the best understandings and greatest circumspection, are guilty of that fault in reasoning which the writers on logic call *the insufficient or imperfect enumeration of parts or cases;* insomuch that I will venture to assert that this is the chief and almost the only source of the vast number of erroneous opinions—and these, too, very often in matters of great importance which we are apt to form on all the subjects we reflect upon, whether they relate to the knowledge of Nature, or the merits and motives of human actions. It must therefore be acknowledged that that art which affords a cure to this weakness or defect of our understandings, and teaches us to enumerate all the possible ways in which a given number of things may be mixed and combined together, and that we may be certain that we have not omitted any one arrangement of them that can lead to to the object of our enquiry, deserves to be considered as most eminently useful and worthy of our highest esteem and attention. And this is the business of the *art or doctrine of combinations.* Nor is this art or doctrine to be considered merely a branch of the mathematical sciences, for it has a relation to almost every species of useful knowledge that the mind of man can be employed upon. It proceeds, indeed, upon mathematical principles in calculating the number of the combinations of the things proposed; but by the conclusions that are obtained by it the sagacity of the natural philosopher, the exactness of the historian, the skill and the judgment of the physician, and the prudence and foresight of the politician may be assisted, because the business of all these important professions is but *to form reasonable conjectures* concerning the several objects which engage their attention, and all wise conjectures are the results of a just and careful examination of the several different effects that may possibly arise from the causes that are capable of producing them."

When we apply this theory to facts we are astonished at the results. Speaking of "the variety of logical relations which may exist between a certain number of terms," Prof. W. Stanley Jevons says:—"Four terms give 16 combinations, and no less than 65,536 possible selections from these combinations; . . . for six terms the corresponding numbers are 64 and 18,446,744,073,709,551,616. Considering that it is the most common thing in the world to use an argument involving six objects or terms, it may excite some surprise that the complete investigation of the relations in which six such terms may stand to each other should involve an almost inconceivable number of cases. Yet those numbers of possible logical relations belong only to the second order of combinations."

If the facts of Nature be so numerous we can never hope to know them all. Perfect knowledge is for us impossible: how, then, are we to make the most of that partial knowledge which we can alone attain to? How can we measure the extent of our knowledge of any subject? By means of the theory of probability.

Although perfect knowledge is impossible, yet we cannot be content with the accumulation of mere isolated facts. We attempt to group facts together, to form theories, and to apply these to the explanation of newly discovered facts. The theory of probability must guide the mind in gauging its knowledge of any group of facts. And the theory of probability is, as Laplace has said, "good sense reduced to calculation."

Suppose it be required to determine the atomic weight of an element, we devise various methods of measurement, we repeat the measurements again and again, but there are nevertheless errors inherent in each method, errors in the instruments employed, and errors in our readings of these instruments, &c. The result can never be more than approximately correct, and the results obtained by the different methods will not be exactly the same. We do not therefore

know the true atomic weight of the element; but the theory of probability enables us to assign to each result its comparative trustworthiness, and so to deduce the numerical probability of the average result being absolutely correct.

The application of the theory becomes often very difficult. Our knowledge is at the best so limited that it is difficult to assign to two propositions their relative probabilities. When we deal with simple numbers, as those obtained in the illustration given, we can apply the theory with comparative ease; but when we come to more complicated questions in physical science we find it almost impossible to obtain sufficient, and sufficiently reliable, data to enable us to estimate probabilities. But, as Prof. Jevons has pointed out, "Nothing is more requisite than to distinguish carefully between the truth of a theory and the truthful application of the theory to actual circumstances. As a general rule, events in Nature or Art will present a complexity of relations exceeding our powers of treatment. The infinitely intricate action of the mind often intervenes, and renders complete analysis hopeless. If, for instance, the probability that a marksman shall hit the target in a single shot be 1 in 10. we might seem to have no difficulty in calculating the probability of any succession of hits: thus the probability of three successive hits would be one in a thousand. But, in reality, the confidence and experience derived from the first succesful shot would render a second success more probable. The events are not really independent, and there would generally be a far greater preponderance of runs of apparent luck than a simple calculation of probabilities could account for. In many persons, however, a remarkable series of successes will produce a degree of excitement rendering continued success almost impossible."

We must be content with partial knowledge.

In ascending from facts to generalizations, which generalizations are more or less probably true, we must make use of hypotheses; we must accumulate facts, make an hypothesis to explain them, and test the hypothesis by appeal to facts.

The investigator of Science must begin with facts; he must end with facts; but between the two he must interpolate hypothesis. He looks at a number of facts; gradually he sees, or thinks he sees, a light dawning on him—a central idea round which all the facts group themselves in a luminous whole. But he does not stop here; he again appeals to facts. He says "If my hypothesis be correct this or that fact must follow." Then he tries experiment. Is the predicted fact really a fact? By the test of experiment he is content to abide; he knows that Nature—however hard sometimes it is to make her answer at all—never answers except truly.

Hypotheses must be used in Science, but hypotheses may be abused. What, then, are the marks of a good hypothesis?

An hypothesis must be workable; it must not go against any well-established scientific generalization, and it must be ready to submit to have its predictions proved by strictly experimental methods.

A good scientific hypothesis must be workable; that is, it must allow us to make determinate predictions—predictions which can be proved or disproved by experiment. A vague generalization, which does not allow of definite deductive reasoning, can have no place as a scientific hypothesis.

A good scientific hypothesis must not be opposed to any well-established generalization of Science. This statement may probably be called in question by many. It is no uncommon thing to find people talking of the way in which Science sweeps aside all preconceived ideas, all Old World notions, all long-cherished delusions. And this is very true; only these people, I am afraid, forget the other side of the case; they forget that did Science present us with nothing but change succeeding change, doctrines swept away and replaced by others to be themselves removed as Science advances, Science would have no claim on our acceptance. It is because Science is at once prolific of changes, and conservative in the extreme, that she has accomplished her work in the world.

We know so little of Nature that we must be ready at any moment to give up that which we had supposed we did know; and yet we have such trust in the stability of Nature that we must cling to those theories which have been gained

by slow accumulation of facts, until there is absolute experimental proof of their falsity.

Such a theory as that of the Conservation of Energy is the general expression of a vast number of facts: it explains these facts; it is a well-established generalization of Science. If we are seeking to explain a number of newly-discovered facts, it is evidently our duty to frame an hypothesis which shall not be itself out of keeping with this theory of the conservation of energy. For if we do not do so we are very probably assuming the incorrectness of that great body of facts upon which the theory rests. It would in most cases be almost better to distrust our personally-observed facts than to distrust so well-founded a generalization. This is one view to take of the question. But, on the other hand, the theory of the conservation of energy is a theory only: it is probably true; we do not, and cannot, know whether it is or is not certainly true. If the observed facts, after the most careful observations, still remain unmoved, and if they are apparently opposed to the generally-accepted theory, the better method will doubtless be complete reservation of judgment until further experimental data is forthcoming. If the observed facts are, however, absolutely opposed to the theory, and if these facts cannot be gainsaid, then the theory must go; it has done its work, and must be supplanted by a wider generalization. The scientific investigator must therefore cling to theory, and yet be ready to abandon theory at the call of fact.

It is, it seems to me, of the utmost importance to insist on this view of the work of the student of Nature; to declare that he trusts Nature altogether, but he distrusts his own powers of comprehending the workings of Nature; that he feels that all things are changing, but he nevertheless clings to what he can grasp of the changeless. The frame of mind of the man of Science is, then, at once opposed to those who would have us believe that "victorious analysis" has now at last reduced all things under her feet, and to those who would have us accept the teaching of authority in place of the teaching of facts. Both alike assume a vast amount of knowledge which neither is possessed of. But the last characteristic of a good scientific hypothesis is its readiness to submit to have its predictions proved by strictly experimental methods. Every newly-discovered fact which is capable of explanation in terms of an accepted hypothesis adds something to the *probable* truth of that hypothesis. Every newly-discovered fact which cannot be explained in terms of the hypothesis takes away something from the probable truth of the hypothesis. We may observe facts which are apparently opposed to the hypothesis which we have provisionally accepted, and yet we may not be justified in condemning the hypothesis, because these facts may either be but partially examined by us, or the hypothesis may not have been fully grasped in all its bearings. But if the hypothesis is to hold its ground there must be no experimentally demonstrated fact, the existence of which would be impossible were the hypothesis correct. To take an instance:—The upholders of the Phlogistic theory affirmed that when a metal is burned it parts with phlogiston; that the product of combustion is metal *minus* phlogiston; and that the re-transformation of the product of combustion into metal is brought about by the absorption of phlogiston. The upholders of what might be called the Oxygen theory affirmed that when a metal is burned it combines with oxygen; that the product of combustion is metal *plus* oxygen; and that the re transformation of the product of combustion into metal is brought about by the removal of oxygen. Each hypothesis had facts in its favor; each explained many facts. But the fact discovered by Davy, in 1807, that the metals potassium and sodium are actually produced by the removal of oxygen from those substances which are themselves formed when these metals are burned, could *not* be explained in terms of the phlogistic theory. Either the fact or the theory must give way. The fact was established beyond a doubt; therefore the theory—in its then accepted form at any rate—had to succumb.

A good scientific hypothesis must, then, be in keeping with facts; but it does not follow that it must be simple, or that it must make no claims upon our belief. The hypothesis which well explains the facts concerning light is, we

might almost say, absurd in the demands which it makes upon our credulity. "We are asked by physical philosophers to give up all our ordinary prepossessions, and believe that the interstellar space which seemed so empty is not empty at all, but filled with *something* more solid and elastic than steel, As Dr. Young remarked, 'the luminiferous ether pervading all space, and penetrating almost all substances, is not only highly elastic, but absolutely solid.' Sir John Herschel has calculated the amount of force which may be supposed, according to the undulatory theory of light, to be exerted at each point in space, and finds it to be 1,148,000,000,000 times the elastic force of ordinary air at the earth's surface, so that the pressure of the ether upon a square inch of surface must be about seventeen billions of pounds. Yet we live and move without appreciable resistance through this medium, indefinitely harder and more elastic than adamant. All our ordinary notions must be laid aside in contemplating such an hypothesis; yet it is no more than the observed phenomena of light and heat force us to accept."

Again, the hypothesis of Gravitation forces us to believe that a particle of matter here, on this earth, is at this moment acting upon each other particle of matter in the universe, and that apparently with an action to which time counts as nothing, and the mass of all the planets as a thin screen offering really *no* opposition.

When we come to examine the hypotheses of Science, we find that they have been developed to very varying degrees of perfectness. "Where, as in the case of the planetary motions and disturbances, the forces concerned are thoroughly known, the mathematical theory is absolutely true, and requires only analysis to work out its remotest details. It is thus in general far ahead of observation, and is competent to predict effects not yet even observed, as, for instance, lunar inequalities due to the action of Venus upon the Earth, &c., to which no amount of observation, unaided by theory, would ever have enabled us to assign the true cause. . . . Another class of mathematical theories, based to a certain extent upon experiment, is at present useful, and has even in certain cases pointed to new and important results which experiment has subsequently verified. Such are the dynamical theory of heat, the undulatory theory of light, &c. . . . A third class is well represented by the mathematical theories of Heat (conduction), Electricity (statical) and Magnetism (permanent). Although we do not know *how* heat is propagated in bodies, nor *what* statical electricity or permanent magnetism are, the laws of their forces are as certainly known as that of gravitation, and can therefore, like it, be developed to their consequences, by the application of mathematical analysis.

If it be impossible to group together the facts of Nature in every possible combination, and then to infer general laws; if it be necessary to make use of hypotheses, it may be asked—Is there no method applicable for forming these hypotheses? nothing to guide us in our guesses at Nature's laws? Of course it would be impossible to lay down *rules* for making hypotheses, just as it would be absurd to *teach* a man to be a genius; nevertheless, if we study the trains of thought by which the most eminent naturalists have been led to their great discoveries, we can arrive at some general idea of the methods which they have followed. These discoveries have evidently been guided by analogy. From one similarity, or from a few similarities noticed between different substances or between different sets of facts, they have inferred the existence of more points of similarity; they have then framed hypotheses which have guided them in their subsequent experimental investigations. To take an illustration:—When an electric machine was worked a peculiar smell was noticed; when a stick of moist phosphorus was allowed to remain exposed to air, a similar smell was perceived; when a hot glass rod was dipped into a mixture of either vapor and air, a similar phenomenon was perceptible. From these observed similarities Schonbein inferred that the cause of the peculiar smell was probably the same in each case, and following up this analogy by experimental investigation he discovered ozone—a substance which has played, and is doubtless destined to play, a most important part in general chemical theory.

Many instructive instances of the ap-

plication of analogy are to be found in the science of chemistry; in fact that science is almost entirely founded on more or less general laws which have been deduced by analogical reasoning. The fact that certain elements form groups having many common properties, and more or less sharply differentiated from other groups, has long been known. The further fact that there is, in many instances, a regular gradation in the atomic weights of the members of such groups, seemed to point to a connection between atomic weight and general chemical behaviour of the elements. Many facts were in keeping with this assumption. The connection between chemical properties and change in atomic weight has of late years been much attended to; and it has been shown by Mendelejeff and others that, if the elements be arranged in order of their atomic weights, beginning with that which has the least atomic weight, the general properties—not only of the elements, but also of their compounds—may be regarded as functions of the atomic weights; that, moreover, these functions are periodic,—that is, that groups of elements may be formed in order of increasing atomic weights, and that the general relations existing between, say, the third member of group two and the other members of the same group correspond with those relations which exist between the third member of group four and the remaining members of this group. Following up the analogy, Mendelejeff has propounded an hypothesis which goes under the somewhat ambitious title of the *periodic law*, and from this hypothesis he has made certain predictions. Among other predictions he has foretold the existence of elementary bodies other than those we are acquainted with: he has even ventured to assign certain properties to some of these hypothetical elements. Nor have his predictions been altogether unfulfilled. The most recent addition to the chemical elements is the metal gallium: in very many of its properties—in fact in its general chemical behavior, so far as this has been experimentally examined—gallium corresponds very closely with one of Mendelejeff's hypothetical elements. We have here an example of an hypothesis founded on analogical reasoning.

But analogy may mislead; it has often misled men in framing hypotheses. As telescopes were made of greater and greater power, astronomers found that the nebulæ were resolved into clusters of stars. One by one these apparently gaseous masses were proved to be really aggregations of solid matter. Analogy suggested that all nebulæ would be resolved when sufficiently powerful instruments could be brought to bear upon them. But meanwhile a new method of research was discovered; and by the use of spectrum analysis Huggins has proved that certain nebulæ really consist of gaseous matter, and has therefore shown that the analogy in the structure of these bodies was not so complete as was supposed.

Analogy must evidently be used with caution. And here again we perceive the need of genius in Science. The ordinary man may amass facts, may even trace out a few analogies between groups of facts, but it is only the man of genius who will discover *the* analogy which will guide to great generalizations. Very probably even the genius will follow many false scents; but if he be a true student of Nature, besides being possessed of the divine gift of imagination, he will test his hypotheses framed on analogical reasonings by appeal to facts, and he will discover the true analogy and frame the correct hypothesis at last

Of the vast masses of facts which are presented to the enquirer in each branch of Science there will be some of more value—considered as guides in deducing general laws—than others. Not unfrequently it happens that it is the fact which somehow refuses to fit in with the generally accepted hypothesis which becomes the means of guiding the investigator to a new and wider hypothesis. "When, in an experiment, all known causes being allowed for, there remain certain unexplained effects (excessively slight it may be), these must be carefully investigated, and every conceivable variation of arrangement of apparatus, &c., tried, until, if possible, we manage so to exaggerate the residual phenomenon as to be able to detect its cause. It is here, perhaps, that in the present state of Science we may most reasonably look for extensions of our knowledge; at all events we are warranted by the recent

history of natural philosophy in so doing."

As an illustration of the use made by genius of "residual phenomena" I might cite the discovery of the planet Neptune by Adams and Le Verrier. Slight anomalies were observed in the motions of Uranus: these were studied; the hypothesis was framed that the peculiar movements were due to the presence of an unknown body; observations were carried out, and the new planet was discovered.

Almost every science presents us with residual phenomena awaiting explanation. To mention one in chemical science. Why are the densities of the vapors of phosphorus and arsenic twice as great, and the densities of the vapors of mercury and cadmium one-half as great, as all analogical reasoning would lead us to imagine they should be? Here is an unexplained fact which will doubtless one day be prolific of consequences.

I have thus attempted to sketch the main points in that method which has been, and is, pursued by scientific men in their attempts to discover the truths of Nature: in conclusion I must say a few words regarding the limits of scientific method.

In science we start with facts, we then form hypotheses which we test by appeal to facts. But so great is the number of facts presented to us that we cannot observe or experimentally determine more than a small, almost an infinitely small, portion of them. Much less can we hope to form satisfactory hypotheses which shall explain them all. This is true in physical science. The mass of facts gathered together by the naturalist is already extremely large; but there can be no doubt that the number of the unknown vastly exceeds that of the known facts of Nature. And of the known facts how few have as yet been explained. The problem of the "mutual effects of three bodies, each acting on the other under the simple hypothesis of the law of gravity," can scarcely be said to be yet completely solved. And if this comparatively simple case has puzzled the ingenuity of the mathematicians what are we to say to the application of mathematical processes to the explanation of those motions and mutual actions which we have reason to believe are being performed and undergone by the constituent portions of every chemical atom? Each of these particles, Sir J. Herschel has remarked, is continually solving differential equations, which, if written out in full, might perhaps belt the earth.

In physical science our ignorance is practically infinite as compared with our knowledge; and when we come to mental and moral phenomena we are almost without any data on which to base strictly scientific reasoning. Each human being presents the phenomenon of a mass of conflicting hopes, fears, desires, passions, and inclinations which science can never hope to classify. How shall we measure these mental phenomena? How shall we weigh accurately the emotions even of the least emotional of human beings? What units shall we employ? How shall we calculate the effects of each human life upon the general life of the community? We cannot hope ever to reduce these things within the grasp of rigid quantitative analysis. As Prof. Jevons has truly remarked:—"As astronomers have not yet fully solved the problem of three gravitating bodies when shall we have a solution of the problem of three moral bodies?" And shall "victorious analysis" ever dream of attempting to bring under her formulæ the facts concerning man's relation to the physical world around him? If each set of phenomena, physical and mental, considered apart from the other, far surpasses our powers of investigation, how can science ever hope to approach the problem of the mutual relations of the two? "The air itself is one vast library, on whose pages are for ever written all that man has ever said or even whispered. These, in their mutual but unerring characters, mixed with the earliest as well as the latest sighs of mortality, stand for ever recorded—vows unredeemed, promises unfulfilled, perpetuating in the united movements of each particle the testimony of man's changeful will." We cannot solve the mystery of the physical world, nor the mystery of the mental world, nor the mystery of the connection between the two.

But we do attempt nevertheless to lessen the sphere of our ignorance and to change the unknown into the known. We endeavor to explain facts by group-

ing them together under a generalization. The wider generalizations of science are generally called laws. Having made a bold generalization, having appealed to facts and found that our generalization stands the test in any instance, we are very liable to conclude that this generalization *must* hold good in all cases, and to give to the expression a *coercive* value. Indeed, the name *law* almost implies coercive power. But are we justified in doing this? To say that the law must hold good in all cases implies infinite knowledge: we may have proved the law to apply in every instance which we have examined, but there is the chance that in the next instance it will fail. Prof. Jevons shows that "no finite number of instances can warrant us in expecting with certainty that the next instance will be of like nature." Every fresh instance of like nature to the preceding increases the probability that the law will hold good in all instances, but after all it is only a probability that we have gained. "The laws of Nature, as I venture to regard them, are simply general propositions concerning the correlation of properties, which have been observed to hold true of bodies hitherto observed. On the assumption that our experience is of adequate extent, and that no arbitrary interference takes place, we are then able to assign the probability, always less than certainty, that the next object of the same apparent nature will conform to the same law."

We speak of matter obeying the law of gravity. In this proposition we imply the existence of two things—matter and force; matter, a *something*, acted on by *another something*, force. Of these two things we cannot give very good definitions. Matter is "that which can be acted upon by, or can exert force;" and force is "any cause which tends to alter a body's natural state of rest, or of uniform motion in a straight line." But the force of gravity acting on particles of matter does not necessarily cause the actual approach of one body towards another; the action of this force upon a given particle of matter is conditioned by the number, mass, distance, and relative position of all the other particles of matter within the bounds of space at the instant in question. We must not forget that the action of the laws of Nature upon the matter of the universe is dependent upon the *collocations* (as Dr. Chalmers expressed it) of that matter at any moment of time. Given the same laws and the same mass of matter, but let the initial collocations of that matter vary, then the results would be altogether different for each collocation. No single law of Nature can be supposed to act independently of other laws. Every law is conditioned in its action by other laws. Or, perhaps, we should say that, in our ignorance, we are obliged to speak of special laws acting and reacting upon one another, when to infinite knowledge all would appear as under the control of but one law. But by us, at any rate, various laws must be recognized; and these are mutually related. Now if we cannot hope to know all the facts of the universe still less can we hope to comprehend all the laws thereof, and much less can we dream of arriving at a knowledge of the mutual actions of those laws upon one another, and the modifications in the action of one law upon material objects introduced by the interference of another law, or of other laws. And even our knowledge of individual laws is but approximative: the more carefully Nature is examined the more reason have we for disbelieving in the simplicity of her actions. At first everything appears chaotic; then facts group themselves together, generalizations are made, laws are framed. But after a time, as investigation proceeds, and as more exact methods are introduced, the law is found to be not quite in keeping with facts; the formula was only approximately true. There are slight exceptions, so slight that the older and ruder methods of research failed to detect them: the law is not rigorously exact. In the hands of the trained and able naturalist these small exceptions often prove stepping-stones to higher generalizations, which embrace in their enunciation the less widely applicable generalization. But if every improvement in our methods of research serves to point out exceptions to what were formerly accepted as general laws, are we entitled to assume that we have *now* reached the true generalization? Would it not be more becoming the spirit of true science to acknowledge our

ignorance, to remember that while we have made one step nearer the goal, that goal is itself still at an infinite distance from us?

I might illustrate this subject by reference to the researches of Caigniard de la Tour and Andrews upon the physical properties of gases, wherein it is shown that the laws in which Boyle, Marriott, and former experimenters enunciated the results of apparently complete investigations into the same subject were really only approximations to a solution of the problem. More recently Mendelejeff has shown, by very refined and laborious experiments, that Boyle's law is not strictly true, and he has paved the way for a higher generalization. But space forbids me to enter into these details.

We generally regard a well established physical law as acting continuously throughout all past time. Of course this is merely an assumption, yet it is an assumption which is apparently necessary in most cases if we are to attempt a scientific solution of the problems of the Universe. But there are good reasons for believing that certain very well established generalizations of science may not have held good during all past time. Sir Wm. Thomson has shown how to deduce (from Fourier's "Theorem of Heat") in certain cases the thermal state of a body in past time from its known condition at present, and one of the results of his investigation is the indication of "A certain date in past time such that the present state of things cannot be deduced from any distribution of temperature occurring previously to that date, and becoming diffused by ordinary conduction. Some other event beyond ordinary conduction must have occurred since that date in order to produce the present state of things. This is only one of the cases in which a consideration of the dissipation of energy leads to the determination of a superior limit to the antiquity of the observed order of things."

It is possible to imagine a law which should exhibit a break, or breaks, of continuity. Babbage has shown that it is theoretically possible to devise a machine which shall work according to a fixed law for any finite period of time, and yet at a fixed moment exhibit a single breach of the law. The machine might, for instance, be constituted so as to continue counting the natural numbers for an immense period of time. "If every letter in the volume now before the reader's eyes," says Babbage, "were changed into a figure, and if all the figures contained in a thousand such volumes were arranged in order, the whole together would yet fall far short of the vast induction the observer would have had in favor of the truth of the law of natural numbers. . . . Yet shall the engine, true to the prediction of its inventor, after the lapse of myriads of ages, fulfil its task, and give that one, the first and only exception, to the time-sanctioned law. What would have been the chances against the appearance of the excepted case immediately prior to its occurrence?"

In the application of scientific generalizations we assume that the future will be as the present; we overlook, necessarily, the chance of sudden interferences with the present order of things. Yet we have no ground for denying the possibility of such interferences. There are facts which make the existence of numerous dark bodies in space very probable. How do we know that by the collision of one of these unseen bodies with this planet the present order of things may not be suddenly terminated? Have we investigated all the hidden springs of energy within the earth itself? Is there no chance of a sudden outbreak of some kind which will destroy this world and all its inhabitants in the twinkling of an eye? These suppositions are not unscientific; it is unscientific to assume complete knowledge when we really know almost nothing.

I think I have said enough to show that the scientific method is necessarily limited; that it leads us to recognize our own ignorance and the vastness of the problems presented for solution.

In an early part of this paper I said that by the aid of science we rise from the changing to the changeless; but if what I have said concerning the limitations of scientific laws, and concerning the unknown possibilities of Nature be true, it would appear as if the firm standing-ground we had seemed to gain were vanishing from under our feet. In a sense it is so; in another, and higher sense, the ground remains sure and firm.

Science, when we know our littleness and the greatness of Nature, exhibits to us the reign of law, but bids us beware of placing our partial interpretations upon her laws; she commands us to proceed in the investigation of facts, but to be very careful how we interpret these facts. We have learned enough already to lead us to believe that although we can never fathom the mysteries of the Universe, the Universe is nevertheless obedient to order. If that little portion of the Universe which Science has conquered to herself be so wonderful in its organization and in its working what must the whole universe be?

STEEL FOR SHIPBUILDING.

From "The Engineer."

THE enormous strides which have been made during the last few years in the manufacture of steel have, almost entirely, removed the objections which formerly were urged against its employment for shipbuilding purposes. Long ago it was felt that if steel could only be made so as to be thoroughly depended upon, and at a moderate cost, it would become a most valuable material for ship building, both on account of its great ductility, and from the additions which might be made to the carrying power of ships in consequence of the weight of steel scantlings being fully 20 per cent. less than that of iron of equivalent strength. Unfortunately, however, the difficulty of securing uniformity of quality and the great amount of nursing required during manipulation to prevent it from altering in its quality while being punched and sheared, as well as the necessity of annealing it afterwards in order to reduce it to its original temper, have hitherto debarred shipbuilders from freely employing it. The question of its use was discussed as long ago as 1868, by the Institution of Naval Architects, on which occasion Mr. Rochussen, of the Hoerder Iron and Steel Works, Westphalia, in his remarks on that subject, expressed an opinion which we knew him to hold, and probably with justice, that steel was not reliable, and not homogeneous, and that people who have spent a life in successfully treating iron, point with scorn at a steel plate which has split or snapped under circumstances where iron would not have sustained any injury. Thus steel yards have snapped in the truss, topmasts split in the fid holes, plates cracked on a sharp curve, and, saving the possibility of bad material inherent to all human production, the quality of the steel may for all that originally have been unimpeachable. Steel had to be saved from its friends. The belief in its breaking strain was at first, unfortunately, based upon the knowledge of tool steel, and it was not uncommon to specify in construction steel equal to 42 tons to 45 tons per square inch. Happily, proper attention has been more recently paid to the peculiar nature of the material. Dr. Siemens has rightly pointed out that it is necessary that those who use it should know what it is, "for," he says "we hear of comparative results of steel and puddled iron as produced in one furnace and another furnace, and one would naturally come to the conclusion that steel was a definite compound, varying only as regards quality. But steel in the form of a needle, or an edge tool, or a punch is of a hardness approaching that of a diamond, and steel in the form of a spring is of an elasticity unequalled by any other metal, or any other substance in nature. Then, again, steel in the form of a rolled plate is, with few exceptions, the toughest material in existence, tougher than copper or wrought iron, and can be moulded into almost any shape in a cold condition. It is therefore of primary importance that you should understand first of all what quality of steel you have to produce, and that its manufacture and use in construction should be carried on with superior intelligence."

Special attention seems first to have been directed to steel for ship plates at Creusot and Terre Noire, and the confidence of the French Government in it

was gained to such an extent that they employed it throughout the hulls of their ironclads Redoubtable, Tempete, and Tonnerre, with the exception of the outer bottoms and rivets, which were made of iron. But Mr. Barnaby, in his paper on "Iron and Steel," read before the Institution of Naval Architects in 1875, pointed out the extreme amount of nursing which was required in its manipulation and quoted from the pamphlet written by M. Barba, *Ingenieur des Constructions Navales* at L'Orient and published the same year, in which it is stated that "if it is impossible to work the plates without hammering, or without local pressure of great severity, or if the curvature given is considerable, it is necessary to proceed with care and skill to avoid ruptures in the course of the operation. The hammering ought to be done with light blows, delivered over as large a surface as possible; and the curvature ought to be produced not at once, but by successive stages." Commenting on this, Mr. Barnaby very pertinently remarked that a material which needed such care in its treatment would stand but a very poor chance in an ordinary shipyard, and concluded by challenging the steel manufacturers in this country to produce a material which we could use without such delicate manipulation and so much fear and trembling. This challenge was taken up by many manufacturers, with the result that a contract was given to the Landore Siemens Steel-works to supply steel plates and angle bars for the Iris and Mercury, building at Pembroke. This material was subjected to the ordeal of a series of most severe tests, which proved the extraordinary ductility of steel manufactured by the Siemens-Martin process; for these experiments may be taken to apply equally fairly, not merely to Landore steel, but also to that manufactured at Bolton, Sheffield, Workington, and Glasgow. Although in the production of very mild plates and bars the Siemens-Martin process was at first the more successful, equally good results have been since obtained in Bessemer converters, and indeed at Bolton, where both processes are in operation, the Bessemer converter is preferred to the open hearth system. This mild steel is endowed with some peculiar characteristics, which render it more fitted for shipbuilding purposes than even best best iron.

In the first place, its tensile strength is about 30 per cent. greater than that of best best iron, and it has much greater ductility and uniformity, together with a capability of application to any of the purposes to which Lowmoor or Bowling iron have been applied, such as flanged garboards, keel plates, bow plates, &c. Then, again, it is equally strong both along and across the plate, and it is said to be infinitely less distressed by punching closely-spaced lines of rivet holes, even when annealed, than any iron would be.

Of course it is an advantage to anneal the plates after working and bending them, but it is by no means absolutely necessary, as has been sufficiently proved by the quenching test, which consists of heating the plate to a cherry red, and then plunging it into water. Its beautiful surface and freedom from exterior defects also renders this mild steel peculiarly applicable for the outside plates of vessels, and a series of experiments made by M. Gautier at Terre Noire, extending over about three years, established the fact that when exposed to the action of sea water mild steel suffers from corrosion only in the proportion of 60 to 140, when compared with the effect of similar treatment upon iron plates.

The only matter which has to be specially attended to in the employment of steel in shipbuilding operations is welding which requires great care and experience if the welds are of any length—several heats being required—otherwise the same treatment as that given to ordinary iron plates is quite sufficient. For the construction of the top sides of men-of-war, and for torpedo boats, mild steel possesses the great advantage of standing the fire from Gatling guns and rifles much better than iron of equal thickness. So far, we see that the advantage of mild steel over iron for ships is undoubtedly very great, and the only question on which its further employment will depend is the matter of cost of production. Hitherto the price of steel has been so high that the saving in weight, and consequent increase of cargo-carrying power, by reductions of scantlings, has hardly been sufficient to compensate for original increase of cost of construction. The im-

provements, however, which have been made in its manufacture have also been in the direction of simplifying the process of production, and therefore reducing the cost. Already mild steel is much cheaper than Lowmoor and Bowling iron, and hopes are held out by the manfacturers that as the demand increases they will be able to reduce the price much more. That this material has at last been brought to such a state of perfection, combined with cheapness, as to make its application to mercantile ships desirable, has now been recognised by Lloyd's Registry. We last week published a report they had received from their chief surveyor and his assistants, together with notice of a set of regulations they have passed for classing ships built of steel. Hitherto all steel ships have been classed as "Experimental," but we are now glad to see that they are to have a regular class, for we cannot help thinking that the "Experimental" classification helped to kill the use of steel in 1868, and materially kept back its improvment.

A general reduction of 20 per cent. in the thickness of plating, frames, &c., is to be allowed in future in steel ships, and iron is only to be used for rivets, keel, stern, sternpost, rudder, pillars, girders, and top of inner bottoms of the usual size, but no other parts without the special sanction of the committee. The surveyors will have, however, to exercise great care and attention in this reduction of scantlings to make ample provision by means of stiffeners against buckling. This we have no doubt they will do, and steel will now have, we trust, a fair field and no favor. But we would impress upon the manufacturers in this country, that perfect as the mild steel is which they are now producing, they must by no means be content to rest upon their work, for, as M. Gautier's able papers at the last two meetings of the Iron and Steel Institute show, the French makers are still rapidly advancing, and with the great advantage they possess in having the most suitable ores at hand, are likely in the long run to outdistance our makers unless the latter look well to their laurels. That there is a great future for steel in shipbuilding is now evident, and we must congratulate the Admiralty in taking the step they have done in initiating its use, and placing the results of their experience so unreservedly at the service of private shipbuilders, which undoubtedly had much to do with bringing on its improvement to its present state. It must not be forgotten, however, that there is steel and steel, and the greatest caution will be required on the part of makers and purchasers to secure a satisfactory result. Steel has failed disastrously more than once as a material for the construction of ships, and although nothing of the kind need occur again, it must always be borne in mind that steel is a peculiar material to deal with, and very unlike iron in its behavior.

LIGHTING BY ELECTRICITY.

From "Journal of the Society of Arts."

THE discovery of electric induction by Professor Faraday in the year 1830 drew the attention of the scientific world to the possibility of utilizing motive power as a means of generating a current of electricity. Faraday demonstrated before the Royal Society that if a magnetised bar of steel be introduced into the center of a helix of insulated wire, there is, at the moment of introduction of the magnet, a current of electricity set up in a certain direction in the insulated wire forming the helix, while, on the withdrawal of the magnet from the helix, a current in an opposite direction takes place. He also discovered that the same phenomenon was to be observed if for the magnet was substituted a coil of insulated wire, through which the current from a voltaic element was passing; and further, that when an insulated coil of wire was made to revolve before the poles of a permanent magnet, electric currents were induced in the wire of the coil. It is on these discoveries that are based the action of all magneto-electric machines.

Amongst the variety of patents that

have from time to time been taken out, both in England and other countries, for magneto-electric machines, there is no doubt that a large proportion are only slight modifications or re-discoveries of already existing machines. Some idea may be formed of what has been done in this branch of electric science, if we take as types of magneto-electric machines those of Pixii, Saxton, Clarke, Henley, Nollet, Siemens, Wheatstone, Ruhmkorff, Wilde, Pacinotti, Holmes, Breguet, Gramme, and Niaudet. Perhaps, before mentioning the practical application of these machines, more especially as a means of producing the electric light, a few remarks by way of explanation of some of them may not be without interest.

Pixii was probably the first who practically carried out Faraday's discovery and constructed a magneto-electric machine. His machine consisted of a wooden frame, working in which was a small vertical spindle, carrying on its upper extremity a permanent horse-shoe magnet; underneath this, on the lower part of the spindle, was fixed a pinion driven by a suitably arranged bevel wheel, so that, by turning a handle, the magnet was made to revolve rapidly. Directly above the horse-shoe magnet was fastened to the wooden frame an electro magnet; and the poles of the two magnets were brought as near as possible together without actually touching. On the magnet being made to revolve, its poles passed those of the electro-magnet, thus setting up a series of reversed currents in the wire of the electro-magnets. As for many purposes it was necessary that the currents should always be in the same direction, to obviate these reversals a small circular commutator was placed immediately below the permanent magnet and fixed to the vertical spindle revolving with it. On this commutator four springs were made to press; two were connected to the ends of the wire forming the coils of the electro-magnet, the other two springs to the two terminals of the instrument from whence the currents of electricity generated are given off. By a very simple arrangement of commutator, not needing explanation, it will be readily understood how the two springs connected to the coils of the electro-magnet may, through the commutator, be put into alternate connection with the two springs connected to the terminals in such a manner that the + currents are always directed to one spring, whilst the — are communicated to the other; so that one terminal becomes the positive and the other negative.

The electricity generated by this class of machine is not a continuous current, but rather a series of currents in rapid succession; although, when the machine is made to revolve at a high speed, the currents are generated in such quick succession that they form a sufficiently continuous current for many purposes.

In Saxton's machine both the permanent and electro-magnets were placed horizontally, and made to rotate end to end. The proportional size of the electro-magnet, with reference to the permanent one, was reduced, as it has been found experimentally not to be desirable to have so large an electro-magnet, in proportion to the permanant magnet, as had been given in Pixii's machine, while there was a great advantage in increasing the power of the permanent horse-shoe magnet.

These machines were only adapted to laboratory and scientific experiments, for which purpose fair results were obtained.

Clarke's machine (a name frequently erroneously given to all classes of alternating current machines) is well-known in connection with small magneto-machines, more especially such as are constructed for medical purposes. The machine differs somewhat from either that of Pixii or Saxton. Clarke took advantage of the fact that the greatest strength of a magnet is situated at a small distance behind the poles, and not at the extremities themselves, and constructed his machines in such a manner that by placing the electro-magnets at right angles to the permanent magnet, its poles were made to pass over those of the permanent magnet at the point where the greatest strength was to be obtained. The machines were made in a very compact form; a commutator fixed on the spindle carrying the electro-magnets, by a simple arrangement, corrected the reversals of the current generated, so that the electricity obtained at the terminals of the machine was

always made to flow in the same direction.

It was not long after the establishment of the electric telegraph in England, that attention was directed to the feasibility of utilising the current generated by magneto-electric machines, for telegraphic purposes. Mr. Henley about this time, having made several experiments in this direction, succeeded in bringing out then a great novelty, his instruments for telegraphic purposes, whereby the use of a galvanic battery was entirely dispensed with. It was with these instruments that for some time the Magnetic Telegraph Company carried on their electric communication.

The system was after a time, however, superseded by the use of batteries, it not having been found to be so advantageous in practice as had at first been anticipated. Perhaps one of the simplest forms of magneto-electric machine then used for telegraphy was Henley's so-called thunder pump, an instrument employed for ringing bell signals for telegraphic purposes. It consisted simply of an ordinary horse-shoe permanent magnet, above which was arranged a small lever. On one end of the lever was an electro-magnet, the poles of which, when at rest, were touching those of the permanent magnet; by depressing the other end of the lever, on which a suitable handle was attached, the electro-magnet was raised from the poles of the magnet, and by this means a momentary current was induced in the coils of the electro-magnet. The wires from the coils were connected to the line, and so to the bell at the receiving station; thus every movement of the handle caused a ring on the bell, by this means calling attention. Modifications of this instrument were also used to work double needle instruments, and were in practical use for a considerable time.

While speaking of the application of magneto-machines for telegraphic purposes, it may be well to say a few words on those of Messrs. Siemens and Halske, and of Wheatstone. One of the most important improvements in these machines since that of Clarke was the Siemens and Halske machine, first brought out about the year 1854. In this, instead of using the ordinary form of electro-magnet, that had up to that time been employed, it was replaced by a cylindrical bar of soft iron. The bar had four longitudinal grooves cut in it from end to end, its cross section resembling a double T. In the grooves, insulated wire was wound parallel to the axis of the cylinder in such a manner that the iron core and insulated wire formed a complete cylinder. The end of the wire was soldered to the axis of the cylinder, while the other was fixed to a small insulated metal ring at the extremity of the axis; on this ring a spring connected to one of the terminals of the machine was made to press, the other terminal being connected direct to the axis. The poles of a permanent magnet were so formed and arranged that they were made to embrace the cylinder, to which they were placed as close as possible without actually touching. This form of machine, while generating a powerful current, had the advantage, from the close proximity of the iron cylinder to the poles of the permanent magnets, that these did not so readily lose their magnetism, as the iron cylinder, when at rest, acted as a keeper to the permanent magnets. Siemens and Halske's well-known form of A B C instrument is worked by the currents generated by a magneto-electric machine of this construction. Some great improvements have lately been made in the machines, more especially those designed by them for electric-light purposes; in these the permanent magnets are replaced by electro-magnets, actuated by currents generated by the machines themselves. Improvements have also been made in the arrangement of the commutator, whereby the evils caused by the inductive spark are in a great measure reduced.

The Wheatstone machine, familiar to most persons in connection with the A B C instruments in general use on private wires in England, as it is from currents generated from these machines that the instruments are worked, differs in many points from any of those already described; as employed for A B C instruments, they consist in attaching to the poles of a permanent compound magnet a set of four bobbins, the soft iron cores (pole pieces) of which are fixed permanently to the magnet, two to each pole. Immediately in front of these

cores a soft iron armature is placed, and arranged so as to revolve in front of the cores on the handle of the machine being turned. The cores of the bobbins, being fixed to the poles of the magnet, receive polarity from them, thus forming four poles, two of which are south and two north. On the armature in turning, passing in front of these poles currents, are induced in the wire forming the bobbins, and these, by suitable connections, are made to actuate the needle on the dial of the A B C receiving instrument.

One of the chief advantages of this arrangement is that the wire of the bobbins is connected direct to the instrument without the interposition of any commutator, rendering the liability to failure through faulty contact in the commutator impossible.

The employment of induced currents from magneto-electric machines has not, however, in practice, been found to give such good results for telegraph purposes as at first sight might have been imagined. Currents generated by these machines are at comparatively a high state of electric tension, necessitating, accordingly, high insulation; and this on lines of any extent is found difficult to sustain, so that the employment of this class of instrument has been confined in a great measure to private wires and similar short lines; even with these it is found that the insulation requires a good deal of attention to maintain.

The magneto-electric machine, patented by M. Nollet in 1850, but now more generally known under the name of the Alliance machine, was originally intended by the inventor as a means of decomposing water by the currents so generated; the hydrogen gas, produced after having been passed through camphine, or some hydro-carbon oil, to be used for lighting purposes. The inventor also proposed to form an explosive mixture with the hydrogen, making use of the explosion as a means of obtaining motive power, in a suitably arranged engine. It is more than probable that the Alliance machine would never have been brought to anything like a practical success had it not been for M. Van Malderen, a former pupil of Nollet's.

The Alliance machine, as at present constructed, consists of a number of circular gun metal discs, arranged and mounted upon an iron shaft, running in a horizontal position between the bearings of two frames that contain the machine. Near the circumference of each of these disc are fixed a series of 16 bobbins with soft iron cores, arranged equidistant and parallel to the shaft, free to turn with the discs between the poles of eight horse-shoe permanent magnets fixed in the frame. The poles of these magnets are placed radially towards the center of the shaft. The faces of the magnets are placed parallel to the discs, so that in each circumference there are 16 poles, equivalent and corresponding to the 16 bobbins. The machines are ordinarily made with either four or six discs, so that in the one case there would be 64 bobbins and 40 permanent magnets, and in the other 96 bobbins and 56 magnets. On the shaft is a pulley by which the machine is driven by means of a band. The bobbins are connected up in series, and one end of the wire is fixed direct to the shaft, the other to an insulated ring on it, or, as frequently arranged, one part of the shaft is insulated from the other; to these are connected the terminals of the machine.

On setting the machine in motion, it is clear that every time a bobbin passes in front of the pole of one of the magnets, a momentary current will be induced in it, varying in direction according as the pole is either north or south. Thus, in each revolution of the discs as the bobbins will have passed the sixteen alternate poles of the magnets, there will have been induced sixteen alternate currents. The machine is run usually at a speed of 400 revolutions per minute, so that in each minute there will be 6,400 alternate currents generated (about 100 per second).

One of the chief advantages of this machine is its compactness and non-liability to get out of repair; no commutator is used, the currents generated being a series of reversals. For electric light purposes they have in France until very recently been the principal machines used. At the Hève and Grisnez lighthouses they are still employed, as also at many other places for lighthouse lamps, apparently as alternating current machines giving satisfaction. Probably it is owing to their rather high price that

their adoption has not been so universal as might have been expected.

The Holmes machine, first patented in England in 1856, differs somewhat from the one just mentioned in the manner in which the bobbins are arranged; these are held between two brass discs in two or more concentric circles, the bobbins rotating in front of the poles of a number of permanent magnets fixed to the frame and radial to the axis of the machine. By this means the bobbins are passed in quicker succession in front of the poles of the magnets, and so per revolution a greater number of currents generated. This arrangement allowed of the machine being run at a slower speed. A commutator was placed to direct the alternating currents and cause them to be given off from the machine in the same direction.

Since his original patent, Mr. Holmes has made a large number of experiments and improvements in his machines. This machine was the first one used practically in England for the electric light for lighthouse purposes. On the evening of the 8th December, 1858, it was for the first time exhibited from the high light at the South Foreland, and remained at work until the 30th of the same month, after which it was worked at intervals until the 6th of June 1862, when it was permanently fixed at the Dungeness Lighthouse, and there it has since continued to be used.

In designing his first magneto-electric machine for the Trinity Board, Mr. Holmes had considerable difficulties to contend with. It was made a *sine qua non* by the Board at that time, that the speed of the machine should be limited to about 100 revolutions per minute, and driven by a direct acting steam-engine, without the intervention of either strap or band. These stipulations made it necessary to make the machines of a much larger size than anticipated. In this peculiar machine it was calculated that in every revolution eighty-five pounds of soft iron were magnetized, N—S and S—N forty-four times. As the speed of the machine was 110 revolutions per minute, there were, consequently, 4,840 reversals of current per minute.

Great care had to be observed, both in the selection of the steel and manufacture of the permanent magnets for this class of machine, in order, that they might take up and retain a maximum quantity of magnetism. In Mr. Holmes' latest patent, to obviate this, he replaces the permanent by electro-magnets, a part of the current of the machine being utilized for magnetising them. The magnets are made to turn while the bobbins are fixed; these are coupled up in such a manner that he is enabled to take off a number of independent currents and thus supply currents for a number of lights, or other purposes, from the one machine.

Wilde's machine resembles somewhat two Siemens' machines of unequal size, the smaller one being placed on the top of the larger. The current from the small one is used for magnetizing two powerful electro-magnets of the larger machine, these replacing the permanent ones ordinarily used in the Siemens'. Very fair results have been obtained from this apparatus, although the same drawback exists in this as in all alternate current machines, from the difficulty that arises in presenting the injurious effects of the inductive spark at the commutator, which, besides burning away the contacts, causes the machines to heat. Many ingenious arrangements have been brought forward to obviate this difficulty; but although they have greatly reduced the ill effects arising from the inductive spark, they have never been entirely prevented.

The Gramme machine differs essentially from those above described in a point of the greatest importance, viz., that instead of its generating a succession of alternating currents, the current is continuous, and in the same direction; hence the difficulties arising from the inductive spark are entirely overcome. The machine is an important advance in the construction of magneto-electric machines. Looking at its simplicity, it seems curious that the idea of utilizing the principle involved should not have occurred to some of those who have given so much of their attention to the construction of magneto-electric machines.

To understand the principle on which the Gramme machine is based, we must refer to Faraday's original experiment of a helix of insulated wire and a permanent magnet. From this it is evident that, in

passing a magnetized bar of steel through this helix, a current in a certain direction will be induced in the wire of the helix until such time that it has reached the neutral point of the magnet (the center of the bar). Further, the direction of the current will be reversed during the passing of the remaining portion of the magnet.

Now, by way of illustration, against this magnet, which we will call A, let another similar one, B, be placed with their like poles touching, supposing, so to speak, that there is thus formed one long magnet with a similar pole at each extremity, and the contrary pole at the point of juncture of the two magnets. In passing the compound magnet thus formed through the helix it will be observed, from what has been above stated, that whilst A is being passed through the helix a current will be induced in one direction, until it has reached the center of A, when the direction of the current will be reversed, and remain so until it reaches the center of B, when it will again be reversed to its former direction.

Now, in the place of the bar-magnet, let us take two magnets bent into half-circles, and place them with their like poles touching, forming thus a ring in which the two poles N and S will be on opposite sides of the ring. The neutral points of the magnetized ring will, therefore, also be on opposite sides, and a line drawn through these would be at right angles to one drawn through the poles, cutting it at the center of the ring. In passing a helix of wire once round the ring, it will be observed that during each half of the revolution an opposite current will be induced in the wire of the helix, the current altering in direction each time the helix passes the neutral points.

In the Gramme machine, for this ring magnet is substituted a ring of soft iron (usually composed of a number of wires) made to revolve between the poles of a permanent magnet. By this means the iron of the ring becomes magnetized by induction, the poles remaining always in the same relative position to the magnets, at no matter what speed the ring may be made to revolve. The neutral point of magnetism in the ring would, therefore, be situated in a line drawn at right angles to one drawn through the poles. Round this ring of soft iron are wound a number of bobbins of insulated wire, connected to each other in series, so that it forms, as it were, one continuous coil of wire, completely covering the soft iron ring. At the points of juncture of these bobbins, connections are made to each strip of a commutator fixed on the axis of the machine. The commutator is composed of a number of metal plates, insulated one from another, and fixed radially to the axis of the machine. The outside of the commutator is turned true, forming a cylinder, presenting on its surface alternate strips of metal and the insulating material used. Two brushes of copper wire are made to press upon this commutator—one on each side. The connections are so arranged that these brushes will always be in contact with the two opposite bobbins that are at the time in the neutral positions with regard to the induced magnetism of the ring, that is to say, at points equidistant from the two poles.

If the ring, with its bobbins, be made to revolve, it is evident that two currents of electricity in opposite directions will be induced in the bobbins, one in one half of the bobbins on the ring, and the other in the other half. These halves being divided by the neutral points of magnetism the currents would be equal, and, consequently, annul one another, were there no connection made with the commutator; but, as the brushes pressing on the plates of the commutator will be thus connected to the bobbins, it follows that, if the brushes were connected by a wire, a current would flow along this wire equal in quantity to the sum of the two currents generated in the bobbins. In fact, the same phenomenon takes place as occurs in two galvanic elements of equal strength when the like poles are joined together (connected up for quantity); the two currents, being equal with, but opposite in direction, annul one another, no action taking place. When, however, the two poles thus formed are connected to each other, a current is generated in quantity equal to the sum of the two elements, which, in reality, it is.

The brushes are connected to the two terminals of the machine, one to each, and regulated so as always to be in con-

tact with the coils, not breaking contact with one until the contact is established with the next one. By this means, when properly regulated, the current is perfectly continuous, and therefore no induction spark takes place.

The Gramme machines are very compact and complete; every attention has been paid in designing them to render them serviceable for continuous work.

In the small machines for experimental use, permanent magnets are used, the poles being brought down and fixed to soft iron pole pieces cut away so as to embrace a large extent of the circumference of the ring. The larger machines used for electro-plating, electric light, and such like purposes, have the permanent magnets replaced by electro-magnets, which are excited from the current generated by the machines themselves. In practice it is found that these electro-magnets always retain a sufficient quantity of residual magnetism to generate a weak current on starting the machine. This current, passing through the electro-magnets, increases their magnetism and re-acting on the bobbins, increases the current from the machine, which in its turn again acts on the electro-magnets and so on, until the current has reached a maximum strength corresponding in proportion to the speed of the machine. The speed of the Gramme machines varies from about 500 to 1,000 revolutions per minute, according to the object for which they have been designed.

Niaudet's machine is in principle similar to that of a Gramme machine; the current is continuous. In this machine a number of bobbins with soft iron cores are fixed parallel to an axis with which they revolve. The poles of these bobbins turn between the poles of two horse-shoe permanent magnets, one magnet being placed at each end of the bobbins, in appearance somewhat resembling two Clarke's machines placed back to back. The bobbins are joined up in series, with connection made at the point of juncture, to a commutator, similar in principle to that of the Gramme. Two contact springs make the connections to the terminals of the machine.

It is unnecessary to give any further description of the various forms of magneto-electric machines that have been brought out. From those already described a fair idea may be formed of the advance that has been made in this branch of electrical knowledge, with regard to the construction of this class of apparatus. It remains, therefore, to be seen in what manner the electricity generated by this means has been practically utilized.

The earlier machines were little else than philosophical toys, and, excepting for demonstration, were very little used. Probably their first practical application was that for working telegraph instruments. For this purpose up to the present time they have been for certain classes of work in extensive use on short lines. One of the chief objections to a more widely extended use has been, that the currents so generated are at a high state of tension, rendering the insulation of the lines difficult to maintain.

The Gramme machine, with the coils of the ring wound with large wire, giving a continuous quantity current, has been proposed for use in lieu of ordinary batteries for working telegraph circuits. The objections to its use are purely of a practical nature, but until solved they will preclude its adoption for this purpose, although, were it feasible, a great saving both in labor and maintenance would result in large telegraph offices.

Some of the earliest applications of magneto-electric machines were for electro-plating, but their employment was very limited, and confined only to a few isolated cases. Since, however, the introduction of the Gramme, their use has become somewhat more extended for electro-metallurgic purposes. Their use in connection with the electric light is perhaps the one for which they have proved themselves most valuable. They replace batteries expensive both to work and maintain, indeed, so much that, although the phenomena of the electric light was well understood prior to the introduction of these machines, yet no practical use had been made of it. For lighthouse lamps the electric light has proved invaluable. Mr. Holmes, as already stated, was the first who successfully applied it in England for this purpose. The machine was exhibited at the 1862 Exhibition prior to its erection at the Dungeness Lighthouse. In France, the Hève Lighthouse, near Havre, was the first that was fitted up with the elec-

tric light, in 1863; in this case the Alliance machine was employed. In both these instances such good results were obtained that the system rapidly spread. It is now acknowledged to be the best system in every respect in all places where it can be applied.

In utilizing the electric light for lighthouses, or other purposes, there are many points that require attention; and it is, perhaps, not the simple matter that might at first appear. Like everything else, it has its drawbacks and inconveniences as well as its good points. Still, whilst for lighthouses, and for many other purposes, it may be economically applied, yet, with our present knowledge of the subject, it requires a vast amount of further development before we can hope to see our streets lighted up by its means.

To generate the electric current, a motor of some description must be used to drive the magneto-electric machine; the function of the latter, as already explained, being simply that of converting the motive power into electricity. The power required will vary in strength in direct proportion to the current to be generated. For the smallest machines of any practical value for light purposes from two to three horse power is found most convenient, representing about 1,000 candle power.

The usual method of obtaining the electric light, and the principle on which the lamps are ordinarily constructed, is that of employing two carbon electrodes, between the extremities of which a current of electricity is made to flow. In doing this a most brilliant light is produced, depending in intensity upon the quantity of electricity employed. That a uniform and steady light may be maintained, the lamp, which consists of some kind of regulator, has to be so constructed that the carbon points are automatically kept at the same distance from one another; so that the resistance of the circuit remains constant. The three principal functions that a properly constructed electric lamp should automatically fulfill are these:—1st. That on a stoppage of the current from any cause the points of the carbon are brought together, completing the circuit—ready for action on the current being re-established. 2nd. The carbons, when burning, must be held a short distance apart; and 3rd. The carbons must be brought together whilst burning at the same uniform rate as the combustion takes place, so keeping the distance between them constant.

In fulfilling the above-mentioned requirements, the Serrin lamp has probably given the best results, having passed through the stage of a philosophical toy, and been employed for some years past in real practical work. The principle of this lamp is used more or less in all the varieties of electric lamps, and, therefore, from a short description of it, the method in which the lamps are ordinarily constructed will be understood.

The Serrin lamp consists of two carbon holders made of brass, placed vertically one above the other; the upper one, to which the positive pole is attached, is held in position by means of a cross piece fixed to a vertical rod placed a few inches away from the carbon holders. This rod and the lower (negative) carbon holder are made free to move, either up or down, in two brass tubes that are fixed to the top of the case containing the regulating apparatus. On the lower extremity of the rod fixed to the upper carbon holder, is a rack that engages in the teeth of one of the wheels of a small clock-work movement. The end of the rod is so weighted that, by its own weight, it has a tendency to drop, and in doing so turns the clockwork; this, in turning, winds up a chain fastened to the lower extremity of the lower (negative) carbon holder; so that by this means, as the positive holder falls, the negative one rises, and thus brings the carbon points closer together. On the last pinion of the clockwork is a small fly, so arranged that a stop in connection with an electro-magnet prevents the fly from turning so long as the magnet is exerting a certain force. This magnet is circuit with the lamp, and thus, as long as the lamp is burning with a certain regulated current, the fly is held from turning; consequently the carbons are held in their position, remaining so until such time as they have burnt away slightly. This will cause an increased resistance, from the distance between the carbons being greater, when a corresponding diminution of the current takes place, weakening the force of the

magnet; this releases the fly, and allows the carbons to approach one another until the resistance is again regulated, and the magnet sufficiently powerful to stop the fly.

The lamp is very ingeniously arranged, and it would be impossible without diagrams to explain a variety of other details that do so much in establishing its success. Suffice it to say that the lamp is so constructed that, by a neat movement, while there is always a sufficient and surplus force exerted for bringing the carbon points together, at the same time, on the circuit being broken, these carbons are automatically brought together without the possibility of the points getting crushed. When employing a continuous current, the positive carbon is consumed at about the rate of the negative; this is also compensated for in the lamp, so that the light is always maintained in the same position.

One of the inconveniences in using the electric light, is that of the carbons having to be replaced about every four hours. To obviate this, it has been suggested to employ two round discs of carbon slowly revolving, their edges touching, the light being formed between these two edges. The first automatic electric light regulator was, on this principle, made by Thomas Wright, in 1845, afterwards improved by Molt and others, but never sufficiently perfected to render it a success. At the present time, a further modification of the principle by Mons. Regnier, is being experimented upon at Chemin de Fer du Nord, Paris, but with what amount of success it is premature to say. M. Regnier, however, expects to be able by this means to arrange lamps burning for twenty-four hours without alteration.

Notwithstanding the foregoing remarks may at first sight appear to put great difficulties in the employment of electric light for commercial purposes, the system has of late been introduced with very satisfactory results. It has made considerable progress in advantageous application; more, perhaps, so in France than in any other country, the Gramme machine and the Serrin lamp being the system almost universally adopted.

Among some of the principal places in France where the system is at work on a commercial scale, and apparently with success, are, Messrs. Saulter, Lemonier, and Co., lighthouse manufacturers, Paris, in their fitting and turnery shops; the chocolate works of M. Menier at Noisiel, also at his india rubber works at Grenelle (Paris), as well as at his sugar refinery at Roye; Messrs. Cail and Co., engineers, Paris, in their locomotive erecting shops; and the Chemin de Fer du Nord for part of their goods station of La Chapelle.

For out-door work there is no question, in many cases, of the advantage of the electric light. By this means an extended area can be readily lighted up, and this in places where gas, probably, cannot be employed.

It is claimed that the cost of working this system is cheaper than that of gas—and, perhaps, in certain cases, this may be the case—but it is very difficult, for obvious reasons, to draw any comparison between the electric light and gas. There is nothing more misleading than a statement of an electric light being of a certain candle power, when comparing its cost with a number of gas burners. In the one case you have a certain candle power of light concentrated, so to speak, in one small spot, probably not giving the advantage of one-half the light; whereas in the other, with gas, the light being divided, is more diffused.

The deep shadows, where so powerful a light as the electric is used, have to a great extent been successfully obviated by keeping the light raised a good height from the ground. When under cover the walls and roof of the building should be kept whitewashed, and one lamp placed in opposition to another; not using reflectors has been found advantageous.

At the La Chapelle Station the lamp (one being at present used) is enclosed in a large lantern, the sides of which are opaque to about half their height, so that the naked light is not visible from any part of the building. Any use, however, of opaque glass, although diffusing the light, must at the same time diminish its candle power very considerably. With low pitched roofs it is found very difficult to sufficiently diffuse the light.

A few weeks ago, as an experiment illustrative of the value and practicability

of the electric light, the Gramme Company in France undertook to light up the Palais de l'Industrie at Paris by this means.

The building, which has a superficial area of about 2.5 acres, was lighted up by two clusters of six lamps each, naked lights suspended from the roof, distant from each end of the building about one quarter the length. The lamps were worked by 12 small Gramme machines driven by two 25 horse-power engines that were placed outside the building. By this means the entire building was sufficiently well lighted up to enable a newspaper to be read at any part of the building. No inconvenience was experienced to the eye when looking at the lights; their height prevented this. The light had a peculiar white appearance, and colors were as readily distinguishable in it as in daylight. The shadows were very slightly stronger than those of ordinary daylight, and by no means marked. As to the lighting up of the building and its practicability, it was a decided success, although with regard to the cost, in comparison with the gas, there were no means of ascertaining.

In the above special mention has been made of the Gramme machine, as it has been the one most extensively used for lighting purposes; however, with any of the other machines previously mentioned, probably similar results might be obtained, each one having its own particular points of excellence.

At the commencement of last June, some trials of the capabilities of a recent invention, "the electric candle," as demonstrating its suitability for dock purposes, were carried out at the West India Docks, permission having been granted to the patentees by the Dock Company.

The electric candle is the invention of M. Jablochkoff, a Russian engineer officer. It consists of two carbons placed side by side, with a strip of kaolin (china clay) insulating them from one another.

M. Jablochkoff had found that kaolin as soon as it became heated, diminished the resistance of the circuit sufficiently to permit of the electric light being formed between the carbons; also that, by the intense heat concentrated at this spot, the kaolin was volatilized; so that, in fact, when the "candle" was once lighted, it gradually burnt down, much in the same way as an ordinary candle.

The experiment at the docks were, unfortunately, not quite so successful as some that have been more recently carried out in Paris, although, in a great measure, they demonstrated the practicability of the invention.

One of the chief advantages claimed by the inventor is that he is thus enabled to divide the circuit into a number of different lights, as the resistance of the circuit is constant, whereas, by the ordinary system, this cannot be done, it being necessary to have a separate machine for each lamp.

The invention is certainly very pretty and a good deal may be said in its favor; although, as to the practical advantage to be derived from it, with our present knowledge of the subject, and its great superiority over the ordinary system, is an open question.

One thing must not be lost sight of, namely, that the distance to which the current of electricity can practically be conveyed for light purposes is very limited; in fact, about 200 yards is the limit; so that the advantage of dividing the light by means of the electric candle is not so great as at first sight might appear, while the amount of light obtained when the circuit is divided is not so great as when one lamp only is used. True, the light is more diffused, but then a number of lights have to be attended to in the place of one, and the advantage claimed is not evident.

With the electric candle a neat form of lamp is used, which, by means of a simple mechanism, throws a fresh candle into circuit as soon as one has burnt out. The lamp is usually arranged with four candles, each burning about three hours, but the number of candles in the lamp could of course be increased if necessary.

Another plan of electric lights, also the invention of M. Jablochkoff, is that of passing a current of electricity through a piece of kaolin, which is thus rendered incandescent; by this means it is claimed that he can divide the current into a number of lights equal each to that of an ordinary gas burner.

From what has been already said, it is

evident that there are a number of useful purposes to which the electric light may be both advantageously and economically applied, but that the time when it will fill the place of our present system of gas lighting, notwithstanding the rapid advance of electrical knowledge, seems as far off as ever.

ELEMENTARY CONSIDERATIONS BEARING ON THE NATURE AND USE OF MATHEMATICAL FORMULÆ.

By WM. H. BURR, C. E.

Paper read before the Pi Eta Scientific Society of Rensselaer Polytechnic Institute.

A MATHEMATICAL formula is a collection of algebraic symbols so grouped as to indicate the law to which are subject the quantities represented by those symbols. If this definition is a true one, it follows that the existence of a mathematical formula without the existence of law, is impossible, or in other words, a mathematical formula is the exponent of law and order. In a universe of chance, mathematical science could not exist. If either in the subtile operations of the human understanding or in the material phenomena of nature, one fact could not follow another in the logical sequence of cause and effect, then it would not be possible to conceive of the existence of the science of mathematics, for such an operation involves the condition that one thought shall follow another in logical order. The very fact then that the human mind is capable of conceiving the idea of the existence of pure mathematics, is proof positive, not presumptive evidence merely, that the operations of that mind are bound by rigid laws. That is, having given the quantities, by their symbols, denoting the effect of the will and subjective impressions of outward things, and the laws showing their relations to each other, then by a mathematical formula the exact result of that operation called thinking, might be at once determined. Of course those quantities and the laws which govern them are of such a transcendental nature that it is absolutely impossible to co-ordinate them; they approach too closely the ultimate nature of the personality of the individual. Considerations of this nature, however, lead to a field of unlimited extent, which may be successfully explored by the human intellect.

We observe the phenomena of nature and at once detect the fact that under equivalent circumstances the same condition, or conditions of things result, and therefore, it may be predicted to a certainty that if the causes represented in a mathematical formula in a manner shown by the laws which govern them, the effect will be indicated with absolutely unerring accuracy. In fact writing the mathematical formula is nothing more nor less than formulating the relation of cause to effect, or *vice versa*.

We are now in a condition to appreciate the value of a mathematical formula considered in itself. In the first stage of a discussion or of an investigation, the mind does establish certain conditions called premises, either by certain fundamental truths called axioms, or by other truths previously determined by a separate line of proof. After having established the premises, however, the operations become too complex for the unaided action of the imagination, and the mathematical formula must be used as the only way out of the difficulty. It takes up the thread of reasoning where the mind leaves it, and follows it through all complications without even the possibility of error. This formula in its primitive condition, gives expression to the premises only. Any subsequent change in the formula, made according to the mathematical axiom that for equals, equals may be substituted, will give a result which can possibly have no property antagonistic to those expressed in the premises or original question. Whatever be the length or the complexity of the reductions made or changes wrought, so long as that axiom is not violated, then there will be in the result no trace of a

property which is not implied in the primitive condition.

In reality a mathematical formula, is the very essence of logic, occupying a position even above and beyond the syllogism.

Contradictions and absurd results cannot, from the very nature of things, exist in a mathematical formula. Results may be, and often are, arrived at which cannot in the present state of knowledge be translated. Quantities are used to which no definite values can be assigned yet they are treated as if they were limitable, and the results obtained commend the most implicit confidence of the mathematician. These characteristics, however, of the science, simply show how absolutely universal and consequently how intensely practical is its application. Those transcendental quantities which are involved in the use of mathematical formulæ, and of a clear conception of whose nature the human mind is not capable, bear about the same relation to finite quantities, that those things which are not seen in the universe hold to things which are; they are the limits toward which the reason may advance, but which it can never reach.

The importance of all these results may not seem very apparent, but it has a very substantial existence nevertheless. It is very true that all reasoning is not conducted by the aid of a mathematical formula, but it certainly is true that it may be, and it is no less true that all reasoning leading to correct results is equivalent to an operation which would be indicated by a formula applying to the case in question. Without the equation as such the science of engineering could not exist, at all. We might have a continuous girder, for instance, but we should never know what load it would sustain; we might infer that there are points of contra flexure and sections of greatest stress, but we should never know where they are. The reason why a mathematical equation is so valuable to us, as engineers, is because the letters in it stand for the things themselves, for forces and dimensions: they are not imaginary things put down on paper for the purpose of giving the subject mysterious surroundings, as is often confidently asserted by ignorant and so-called *practical* men; nor yet is a formula a mere piece of machinery. Every operation with mathematical formulæ stand for just so much physical reasoning of the highest order,and every formula represents the precise relation in space existing between the quantities under consideration. No formula is thoroughly understood or of any real use to a professional man until these things are thoroughly realized. The correct interpretation of an equation and the discrimination of the proper relation which it holds to his work,are some of the most important duties of the professional man; in truth therein lies the fact that he is truly professional. This point cannot receive too much emphasis. To obtain an equation is one thing, and to understand it is another.

The contempt shown by so-called "practical" men for educated technists and their opinions, is, doubtless, almost entirely based on the fact that the former are incapable from lack of educational training of appreciating the value of a mathematical formula. In fact this distrust of mathematical formulæ is not altogether confined to those who lack scientific training, although it ought not to be found outside of their ranks. The old notion of the antagonism existing between "theory" and "practice," has the same source. It must be confessed that the scientific man himself is too often responsible for this state of things. He proudly points to his formula as the "no-beyond-which;" the authority which is not to be meddled with or questioned under any circumstances whatever; when in reality he utterly fails of his duty. A mathematical operation is not to supplant the reasoning faculties, nor is a formula a blind guide to one's operations, to be used as a dose of medicine is to be taken, trusting that the result will be a desirable one. The most powerful of allies, if intelligently used, becomes a very dangerous thing if handled at random or ignorantly. The meaning of every formula should be interpreted with scrupulous care, for it is the exponent and embodiment of reasoning of absolute accuracy, the very co-ordinating of thought and the determination of one's mental position in regard to the subject that may be under consideration.

For obvious reasons, mathematical work should be as simple as possible. The usefulness of a formula increases

very rapidly with its simplicity. But, on the other hand, when other things are equal, the more profuse a book is in formulæ the more easy to comprehend will it be in the treatment of any given subject. For this reason, the works of Rankine requires the exercise of much more thought than those of Weisbach. Once understood, however, the works of the former possess many advantages over those of the latter.

In the application of a mathematical formula, the greatest care should be taken that the conditions under which it is used are the same as those for which it has been demonstrated. If the dimensions of a girder of uniform resistance be determined in the ordinary manner, such a girder will be a failure, for the formula was demonstrated by ignoring no less a matter than the shearing stress. A confusion of units often vitiates what would otherwise be a correct result. The various steps of a demonstration will indicate whether quantities of the same kind are to be expressed in the same unit or not; but whatever is implied in the demonstration must be used, and nothing else.

The sign of the quantity entering the formula is of no less importance than the unit in which it is expressed.

Leaving the subject as it directly affects us, it may be interesting to take a brief glance at what the elegance and power of mathematical analysis has won for itself in its application to other branches of science.

No less persons than De Gordon and Boole have made successful efforts towards giving the science of logic a thorough mathematical treatment, and it has been put upon a firm mathematical basis by W. Stanly Jevons, of the University of London, one of the greatest thinkers of the age. He does away entirely with the syllogism, by using the simple mathematical axiom, that for equals, equals may be substituted, and actually makes a fallacy impossible.

The same author, Jevons, has gone far toward representing the various quantities which enter into the science of Political Ecocomy by mathematical symbols, and only lacks data, which will be supplied by experience, to make the science capable of exact mathematical treatment.

In various quarters efforts are already being made to reduce chemical reaction to a mathematial basis, and there is the strongest reason to believe that such efforts will eventually be successful.

By one of the most powerful analyses ever made, Helmholtz has shown how the visible universe may have been evolved from a perfect and invisible fluid by certain dispositions and positions of the atoms of such a fluid. In short, as has been said before, whatever operations in the universe are subject to law and order, and there are none other, are capable of being represented by mathematical analysis, though infinitely intricate it may be in many cases.

IRRIGATION IN SOUTHERN INDIA—THE BASIN OF THE KRISHNA.

From "The Geographical Magazine."

The catchment basin of the river Krishna includes a great part of the region which has been the principal scene of the recent famine, and over which the rainfall is less than 30 inches in the year. This dry region comprises part of the Deccan, several districts of the Bombay and Madras Presidencies, all within the Krishna system, as well as that part of Mysor within the basins of the Krishna, Kaveri and Pennair. Consequently the waters flowing from the part of the ghats which overhangs this dry belt have a most important function. Upon its careful storage and distribution depends the existence of the inhabitants of a country 94,500 square miles in extent. For that is the area of the Krishna River basin. The streams whose fountains are in the Western Ghats from about 13° 50′ N. to 19° 50′ N., a distance of 360 miles, all flow into the Krishna, the length of the main river being 800 miles.

The source of the Krishna is in the

Mahabaleshwar Hills, within 40 miles of the western cost of India, together with those of its tributaries the Koina and Yena. The temple of Maha Deo, at Mahabaleshwar, is built at the foot of a steep hill, overlooking a deep ravine, and has an open space in front. The exterior is faced with pilasters painted yellow, the intermediate spaces being red. In the centre there is an arched door-way leading into an interior cloister built round a tank, into which a stream of water pours out of a cow's mouth. This is the source of the river, considered as the deity in a female form, and often spoken of as Krishna Bai, or the Lady Krishna. Tall trees and bushes cover the sides of the hill, such as roses, daturas, and jambul trees with heads of graceful white feathery flowers. The total rainfall, on these hills, which are only 4500 feet above the sea, is 200 to 220 inches.

Descending rapidly from its source, the Krishna flows past the beautiful city of Wai with its temples, and handsome flights of stone steps, and lovely Brahman women. It then enters the Satara district, and commences its beneficent irrigating work, in the face of special difficulties. The rivers, in the Krishna system within the Bombay Presidency, have so slight a slope that their fall would not gain much on that of a canal, while the steep transverse slopes of the valleys prevent canals from being taken to any distance from their parent streams. The rivers are filled at the time of rains, but during the long dry season of eight months they become mere threads. Here the objects are the retention of supplies of water which run to waste during the rains, and the command of the barren lands on the sides of the valleys. The principal work on the upper part of the course of the Krishna is called the Krishna Canal. A dam is thrown across the bed of the river at Kurvar in the Satara district, provided with scouring and regulating sluices. Thence a canal is taken with a slope of a foot a mile, and a course parallel to that of the river at first, but eventually receding from the bank so as to command a larger area of land, the number of acres irrigated being 1,825. Within the same district the canals from the Yerla, Rewari, Chikli, and Gundauli tributaries irrigate 997 acres; and the Magni tank and canal works, 348. The canals from the Yerla River alone, if supplied during the dry season from storage tanks, would irrigate the area of 12,000 acres which they command. The projected Nehn Tank will effect this object. It will require an earthen dam 4,400 feet long, with a greatest height of 63 feet. The drainage area above the tank is 60 square miles, and the average rainfall 24 inches. Another scheme, in Satara, is the construction of the Pingli Tank, on a tributary of the Máu River, in one of the driest tracts of the Deccan, with a fall of only 24 inches. A dam 53 feet high will impound 195¼ millions of cubic feet of water, and the tank will command 3,000 acres by means of the Gundauli Canal.

From the north the Krishna receives the River Bhima, draining, with its tributaries, the Sina, Nira, and Muta, the districts of Ahmednagar, Poona, and Sholapur. The most important work in the basin of the Bhima is that for the water supply of Poona and Kirki. It consists of a masonry dam of great height and 2,900 feet long, at Kharakwasla, across the Muta Valley, to form a reservoir. Two open ducts lead the water to Poona and Kirki, where the water is distributed by iron pipes. The canals are still under construction, and, when completed, will supply a large area with irrigation. The Ekruk tank, four miles north of the town of Sholapur, is on the Adila, another tributary of the Bhima. The dam across the Adila Valley is 7,200 feet long, and 72 feet high in the center, with a waste weir at the east end. A lake is thus formed, with an area of 6½ square miles, and 35,840 acres are brought under its influence by means of three channels. The dam was completed in 1869.

From the south, and within the Bombay Presidency, the Krishna receives the Rivers Gatparba and Malparba, which drain the districts of Belgaum and Dharwar. The Gatparba has an independent course of 160 miles; and about 35 miles north-east of the town of Belgaum the river drops over a perpendicular quartz rock 176 feet high, forming the beautiful Falls of Gokak. In the rains the river is 180 yards wide, and temples, sacred to Mahadeo, are built on

either side of the cataract. There are several proposals for utilizing the waters of the Gatparba and Malparba, by a canal from the former river at Gokak, by a canal from the Malparba into the Dharwar plains, for completing the Kalhola-nullah, Churdi, and Maddak tanks. But the latter scheme is the only one that has been carried out. Belgaum has an area of 4,592 square miles, and a population of 938,750, or 204 to the square mile. Dharwar, in an area of 4,565 square miles, has a population of 988,037, or 216 to the square mile.

Most of the irrigation work in the Bombay districts within the basin of the Krishna has yet to be accomplished. Many great reservoirs for the storage of water, in this part of the basin, might be constructed, besides those which I have enumerated. For instance, Colonel Meadows Taylor, in his journey to Ahmednagar in 1853, mentioned how much he was struck with the capabilities of the country for large irrigation works, and, in particular, for tanks. Streams descending from the table-lands to the north, and flowing into the Sina, afford ample supplies of water, and the ground, from its peculiar character, provides most convenient basins, only requiring dams to be converted into large tanks. Until all this storage work is executed, the people will be exposed to periodical visitations of famine. It must always be remembered that improved communications can only afford the means of relieving, not of preventing scarcity of food.

After entering the territories of the Nizam, the Krishna leaves the table-land of the Deccan, and falls, by a descent of 408 feet in about three miles, into the lower level of Shorapur. Here, in the floods, there is a magnificent broken volume of water, rushing down an incline of granite with a mighty roar, and a cloud of spray dashing up high into the air. The Krishna then receives the Bhima, its chief northern tributary, and forms the northern boundary of the Raichur Doab, until it unites with its great southern affluent, the Tungabhadra. The country of Shorapur, between the Krishna and Bhima, was the scene of Colonel Meadows Taylor's administrative labors from 1841 to 1853, and irrigation received a full share of attention at his hands. His first essay at irrigation works was the repair and extension of the lake at Bohnal, and it proved a complete success. He made it into a sheet of water 2½ squares miles in area. His new tank at Kuchaknur, near Bohnal, has an area of 6¼ square miles, and a dam 1,872 yards in length, irrigating 10,000 *bigahs* of rice.

The great southern tributary of the Krishna, the Tungabhadra, has its sources in Mysor. It is formed by the confluence of the twin streams, Tunga and Bhadra, at Kudali, nine miles N.N.E. of the town of Shimoga. It then flows northwards, receiving the rivers Warda, Choardi, and Kumadvati, and, on leaving Mysor, forms the boundary between the Madras and Bombay Presidencies, with the district of Bellari on the right, and that of Dharwar on the left bank. The Tunga, 149 miles long, has a catchment basin of 1389 square miles, of which area the drainage of 100 square miles is intercepted by tanks; the Bhadra, 160 miles long, has the drainage of 175 square miles, intercepted by tanks, out of an area of 1675; the Warda, forty-seven miles long, has the drainage of 180 out of 610 squares miles, intercepted by tanks; and the Choardi, forty-three miles long, has the whole area of its catchment basin—510 square miles—fully utilized. The Tungabhadra is never dry, and in the rainy season it swells prodigiously, and forms a rapid and muddy stream, ten feet higher than the rocks which stand out in its bed during the dry season. Its four sources, the Tunga, Bhadra, Choardi, and Warda, drain an area of 3754 square miles in Mysor, chiefly mountainous country, with a rainfall of 135 inches in the year. After the united stream enters the plains, it flows through a region where the rainfall is only twenty-four inches. The ancient name of the river is the "Pampa," by which it is mentioned in the Ramayana. The tradition is that Hiranyaksha, son of the Rishi Kasyapa, seized the earth, and bore it down to the lower world; upon which, Vishnu, assuming the form of the *varáha*, or boar, plunged into the ocean and brought up the earth again. The perspiration arising from this exertion trickled down the boar's tusks, and formed two streams, that from the left

tusk being the Tunga, and that from the right tusk the Bhadra.

In the Bellari district the Tungabhadra has long been used for irrigation. At Desanur and Siragupa there are two *anicuts*, by which 2,519 acres are irrigated. Next come the Valabapur and Korragul *anicuts*, being two branches, with an island between. The former is a reconstruction of an old native work, consisting of loose masses of stone. It is now of solid masonry, with *chunam*, and is 994 feet long. The ancient work was built by Krishna Rayel, the King of Vijiyanagar, in 1521 A.D. The Korragul is 400 yards long, of rough native work. Next comes the Ramanagadda *anicut*, across the western branch of the river, opposite the Island of Kuravagadda, and the Kuravagadda *anicut* crosses the eastern branch. The Roya channel is turned out of the river above this *anicut*, and has a tortuous course of 217 miles, ending in the Kamlapur tank. The Bella *anicut* is just above the village of Hossur, an ancient native work, concave towards the stream, only extending from the right bank to an island, and the channel from it is but 4½ miles long, then dividing into several smaller channels. The Turut *anicut* is taken across the river about a mile west of the old city of Hampi, and is formed of a number of bits of masonry, connecting islands and rocks. The channel from it is very tortuous. The Ramsagra *anicut* is an old, rough stone dam, running diagonally up the river, connecting islands and rocks. Its channel is 9½ miles long, and tolerably straight. The Kampli *anicut* also consists of detached pieces. The last dam is called Taumbiganur, whence the Rampur channel flows for seven miles. All these *anicuts*, except the new one at Valabapur, were built by the ancient Kings of Vijiyanagar. The total length of the nine channels taken from them is 89¾ miles. There are also eight large tanks in the Bellari district, securing cultivation to 29,728 acres.

The Kings of Vijiyanagar did all in their power to fertilize the arid region over which they ruled from 1034 to 1524. Abdu-'r-Rizzak, the Envoy of Shah Rokh, in 1441, and the Italian Nicolo Conti soon afterwards, visited Bijayanagar, and both describe the magnificence of this city on the banks of the Tungabhadra, now a silent and desolate mass of ruins. Channels of water flowed through the streets and irrigated the gardens, while the larger channels from the *anicuts* were extensively employed for the cultivation of rice, sugar cane, cocoa nut, turmeric, and especially ginger. Many noble tanks, the largest nearly three square miles in area, were also constructed by the Kings of Vijiyanagar. Abdu-'r-Rizzak tells us that the country was well cultivated and very fertile, and that the city of Vijiyanagar was such that the pupil of the eye has never seen a place like it.

The people of the Bellari district have suffered sorely from the famine, and the English, as the successors of the Vijiyanagar Rajahs, are bound not only to maintain, but to extend and complete the irrigation works. The way is clear, and even detailed surveys have been executed by Mr. Gordon. The Bukkacherla project would have the effect of irrigating 11,000 more acres. The Ruddam project will add 1344 more, the Hindipur project will secure to eleven tanks a regular supply of water; and the Bomanahalli project is designed to form a reservoir capable of storing sufficient water to irrigate 64,000 acres. The water is to be distributed by two channels. Then there are the two schemes of the Madras Irrigation Co. which have not yet obtained sanction. The first is for a canal to be taken from the Tungabhadra at Valabapur, to cross the hills near Daroji by a deep cutting and a tunnel 450 yards long, and then to take a nearly straight line to Bellari. Mr. Gordon completed his surveys for this project in 1867, ten years ago. It would have irrigated 150,000 acres. Another project would lead a canal from the Tungabhadra at Hossur, pass round the hills instead of through them, and thence go to Bellari. It is designed to irrigate 212,000 acres. The whole cost of these works would be £950,000, the interest on which at 5 per cent. is £47,500. In 1854 about four times that amount was wasted by hurried expenditure on famine roads, and by remissions, besides the loss to the people of their crops and cattle. These facts speak for themselves. The famines in Bellari are mainly due to the persistent refusals to sanction the

execution of feasible and well-matured irrigation schemes.

An important tributary of the Tungabhadra, coming from the Mysor district of Chitaldrug, is the River Vedavati, or Hagari. It is formed by two streams, the Veda and the Avati, both rising in the Baba Budan Mountains, and has a catchment basin of 2250 square miles, with a rainfall of twenty-four inches. It flows through the central belt of hills by the pass called Mári-Kanive, and soon after leaving Mysor receives a tributary called the Janagi-halla, or Chinna Hagari. It is a very shallow river, and presents a broad bed of sand in the dry season. The Hagari has a course of 114 miles in Mysor, with a catchment basin of 5,295 square miles, of which 4,097 have their drainage intercepted by tanks, and that of 1,198 is not utilized. The Chinna Hagari is 53 miles long. Out of the 524 square miles of its basin, the drainage of 356 is intercepted by tanks. A number of small channels are drawn from the Hagari, in the Kadur district of Mysor; but the great project which would fully utilize its waters is still neglected. This is the construction of an embankment in the Mári-Kanive gorge, and the consequent creation of an immense reservoir that would irrigate 50,000 acres of the fertile but now arid plains of Hiriyur. At the time of Dr. Buchanan Hamilton's tour in 1800, this Mári-Kanive gorge, in the Chitaldrug Hills, was pointed out as a spot peculiarly favorable for the construction of a dam. But nothing has ever been done, and this is the more to be deplored because large sums have been spent in surveys and measurements. The whole Krishna system, within Mysor, has a united length of 611 miles, and a catchment basin with an area of 11,031 square miles. Out of this, the drainage of 6,217, or 56 per cent., is intercepted by tanks.

After entering Bellari, there are channels taken from the Hagari which irrigate 1,500 acres; and it falls into the Tungabhadra 72 miles above Karnúl. The Pennair is another river which, though not perennial, brings down large volumes of water with its freshes. It has a course of 100 miles in the Bellari district, and the construction of a few *anicuts* would change the face of the country. The Bellari district, with an area of 11,007 square miles, has a population of 1,668,006, or 152 to the square mile.

No region in India is more dependent on adequate supplies of water for the existence of its inhabitants than the Ceded Districts of the Madras Presidency; and when the Madras Irrigation Company was formed in 1866, with a capital of £1,000,000, having interest at 5 per cent. guaranteed by Government, the Ceded Districts were selected as the scene of its operations.

The project of this company was partially sanctioned in 1861. It was to divert, by means of an *anicut* at Sankasala, 17 miles above Karnúl, a portion of the flood waters of the Tungabhadra into the valley of the Pennair, through a capacious canal along the right bank of the former river, and across high land, forming its watershed to the east. But the other parts of the project, including the works for irrigating the Bellari district, and the construction of large reservoirs for the storage of water have not been sanctioned.

The refusal to sanction the construction of these reservoirs ensured the failure of the enterprise. From June to November there is abundance of water available from the Tungabhadra, which now runs to waste. But from November to June not a drop can be allowed to be abstracted from that river without injury to the Krishna delta irrigation. Capacious reservoirs for storage were, therefore, essential to provide for the summer supply of water. One would have been the Mári-Kanive, another would have been in the Hindri Valley, covering an area of 28 square miles, and another at Kara Bellegal, about 30 miles from Karnúl. Large reservoirs were also to have been constructed at Mudaba, on the Tunga; at Lakkawali, on the Bhadra; and at Masur, on the Choardi. But permission to undertake these absolutely necessary works has been refused.

At Sankasala an *anticut*, 12 feet high and 1,500 yards long, was thrown across the Tungabhadra. From its right flank the main canal is carried parallel to the river for 17 miles, with only one bank, from 16 to 34 feet high, the other being formed by the natural rise of the ground. Thus a quantity of land is submerged,

while the single bank is subjected to violent action from the waves, owing to the extensive spread of water. Close to Karnúl the canal is taken across the Hindri River, on a fine aqueduct. At Metakondal, seventy-two miles from Sankasala, there is a cutting a mile long which takes the canal from the Krishna basin, across the water-parting, into that of the Pennair, descending the valley of the tributary Kolair into the Pennair itself, by a succession of locks, in a fall of 236 feet. The canal is completed from the Sankasala *anicut* on the Tungabhadre to the Pennair, a distance of 143 miles, but not so as to be capable of bearing the full amount of water, owing to weakness of construction. Another defect is, that sufficiency of waterway is not provided for the passage of flood waters, either under the canal or by surplus weirs in its banks, for the escape of storm waters entering it when full.

Water was first admitted into the main canal at Sankasala on the 10th of July 1864. In 1866, the original sum of £1,000,000 having been found insufficient, the Secretary of State sanctioned the addition of £600,000 to the Company's capital, also with a guaranteed interest of 5 per cent., on condition that the canal, as far as the Pennair, was completed by July 1871. By that date the main canal was made, all the sluices in it were built, and the channels for distribution were in progress, 216 miles of them, commanding 91,567 acres, being finished. But if the full amount of water was admitted into the canal the embankments and walls would fail at many places. The total expenditure on the canal, in India, up to 1876 has been £1,583,308. The extent of irrigation in Karnúl was 10,420 acres, and in Cuddapa 5,949 acres, total 16,369 acres; and the whole revenue from irrigation amounted to £5,763. There is no marked extension from year to year, and the financial prospects of the canal are most unsatisfactory, not nearly paying its working expenses. The rate charged for water, namely, 6 rupees per acre, is considered to be excessive, for ryots are unwilling to go to the expense of converting dry land into wet, when they have to pay so high a charge.

The Karnúl district has an area of 7,358 square miles with a population of 959,640, or 130 to the square mile; and Cuddapa covers 8,367 square miles with a population of 1,351,194, or 161 to the square mile.

The Tungabhadra, after a course of 213 miles, falls into the Krishna about 81 miles below Karnúl; and soon afterwards the main river approaches the gorges of the Eastern Ghats. In this part of its course the Krishna receives several small tributaries on its left bank, from that part of the Nizam's territory, which formed the ancient kingdom of Telingana. It is now included in the three zillahs or districts of Nulgunda, Kummum, and Eilgundel, which vie with Mysor and the Carnatic in the number of their tanks. Eilgundel is, however, within the Godavari river basin. A splendid system of tank irrigation was established by the ancient Telugu dynasties, and maintained by their Muhammadan successors. The surface of Telingana is undulating, with numerous hollows and depressions suited for tank basins, and detached granite hills crop out in all directions. The drainage from summer rains is stored in tanks, of which there are upwards of 2,000 in the Nulgunda zillah, and as many in that of Kummum. In many places permanency of supply is maintained by channels drawn from rivers or rivulets on the way to the Krishna. Thus a canal from the Musa, near Haidarabad, fills a series of four tanks, one below the other.

The Krishna and the Pennair, after passing through the Eastern Ghats, supply water for two important systems of deltaic irrigation. The upper courses of these rivers and their tributaries traverse the wide belt of arid region, with a rainfall of less than thirty inches, which is exposed to periodical visitations of scarcity and famine. If the necessary storage reservoirs were constructed on the streams which command this region, so as to supply water in the years when the usual rains fail, there would be no more famine. It is quite true that, even if all water was intercepted and none was wasted, nothing like the whole calculated rainfall could be relied upon. Sir William Denison had a careful experiment made at Sydney, in New South Wales, which showed that not more than a quarter of the total rainfall, on a given surface of an average character, finds its

way to the outfall. Still, after all possible allowances, the existing *data* show that, if no water within the Krishna catchment basin was allowed to run to waste, all danger of a recurrence of famine in that region would be at an end.

Karnúl and Cuddapa are divided from the districts on the east coast by the Eastern Ghats, the highest peaks of which attain a height of 3,000 feet. The slopes are covered with low jungle, in some places mixed with bamboo, and in parts timber of good size is met with. The Krishna passes through this chain, and enters the low country about sixty miles from the sea. Below Bezwara, near the entrance of the gorge, both banks spread out into rich alluvial plains. At Bezwara the River Krishna is 1300 yards wide, and has a depth in the dry season of five to six feet, in average freshes of thirty-one, and in highest freshes of thirty-eighth feet. The flood discharge is 1,188,000 cubic feet per second. The Krishna and Godavari have produced the alluvial plain on this part of the east coast of India, and half-way between them is the Colair Lake, a low swampy tract representing the work which the two rivers have to perform before the alluvial plain can be regarded as perfect.

The English acquired this plain in 1766, and for eighty years they did absolutely nothing, while famine and pestilence periodically desolated the region. In 1833, when the rains failed, not less than 200,000 people died of hunger, the Government lost £900,000 of revenue, and the loss of property amounted to £2,500,000. So that neglect of irrigation works is a most wasteful, as well as a life-destroying policy. By establishing channel heads on the river banks at the apex of the delta, and by securing there such a height of water as the levels of the lands to be irrigated may require, the whole tract below is placed under command, and its productiveness is secured to an extent only limited by the volume of water at command. The Krishna delta works affect an area of 2,000 square miles, inhabited by 1,000,000 souls. The river flows along an elevated central ridge, or backbone, with the country falling off gently towards the right and left, and a general inclination to the sea.

At Bezwara, the Krishna flows between hills, with a width of 1,300 yards. The hills furnish an abundant supply of stone for building, and lime is easily procurable. The position is exactly at the apex of the delta, and the height is sufficient for purposes of irrigation. Here the *anicut* has been thrown across the Krishna. The work was begun in 1852. It consists, first, of a broad basis of heavy stones thrown into the river, and allowed to assume its own natural shape, 3,750 feet long, 305 feet broad, 21 feet high in front, and fourteen feet above the summer level of the water. It is faced with a casing of stone masonry, seventy-five feet broad, resting on a double row of foundation walls. The sill is twenty feet broad and five feet thick, of cut stone, bound together with iron clamps, and 1,280 yards long. Under-sluices are provided at the right and left extremities of the dam, for the purpose of scouring out the silt in front of them, and thus keeping an open channel at the heads of the irrigation lines. The total length of each sluice is 132 feet.

On the Masulipatam, or left bank, the main channel from Bezwara breaks into two branches, 900 yards from the head sluices. One runs towards Ellore, thirty-nine miles long, and the other to Masulipatam, forty-nine miles long. The first branch of the Ellore canal opens at the eighth mile, and is called Ryve's Channel, and a branch, nineteen miles long, runs to Gudaveda. Various other channels spread over the delta, in the direction of Masulipatam. On the Guntur, or right bank, the main western channel runs parallel with the river, with two principal branches at right angles, the Vellatur and the Yeskapilli. The Commamur Channel runs south-west, away from the river, and will irrigate 100,000 acres, in a length of fifty miles. The whole length of the principal canals already finished is 254 miles; when completed their total length will be 320 miles. The irrigated area in the delta is 226,226 acres, yielding a revenue of £89,000.

The river Pennair is connected with the Krishna system by the Madras Irrigation Company's canal, and the two rivers may be appropriately treated of together. The Pennair rises in the north

of Mysor, describes a curve through the Bellari district, flows through Cuddapa, and falls into the sea about nineteen miles below the town of Nellor. Its length is 355 miles, and the area of its catchment basin 20,500 square miles. During the course of ages the Pennair has formed for itself a delta of alluvial soil, peculiarly well adapted for rice crops, in the district of Nellor, the area of which is 8462 square miles, with a population of 1,376,811 souls, or 163 to the square mile. In former times numerous tanks were formed by the natives, to supply water for their crops, and small irregular channels were led off from the river. But in 1855 an *anicut* was constructed across the Pennair at Nellor, in order to secure a good and certain supply of water for all the tanks. In 1857 the flood waters rose to such a height and did such damage that a second dam was built. This also failed, and the present *anicut* designed by Sir Arthur Cotton was completed in 1863.

It is 677 yards long, with the crest nine feet above the bed of the river. Hitherto it has stood admirably. The Pennair comes down impetuously in bursts of short duration, so that with a precarious river of this kind it is necessary to keep a reserve of water by means of the Nellor and other tanks. Thus the system consists of an *anicut* and a series of tanks, water being given direct from the *anicut* so long as there is water in the river. The supply channels are so adjusted as to discharge into the tanks until they are full, and then to supply the land direct. The irrigated area is only on the left bank, the levels on the northern side being too high.

The water supply under command will irrigate 64,000 acres, the quantity allowed per acre being 2¼ cubic yards per hour; and this will be supplied for 150 days, which is ample time for a rice crop to come to maturity. There are three main channels issuing from the primary feeder, called Jaffer Saib's, Krishnapatam, and Savepalli; under the two first 34,000 acres being cultivated, and under the last 30,000.

There are several more smaller rivers in the Nellor district which can be utilized for irrigation. A large reservoir could be formed near Gandepalem, which would be of immense use to the people, and where a tank existed in former times. Throughout Nellor there are 975 tanks, yielding a revenue of £94,000, fed by small rivers and streams which rise in the Eastern Ghats. During the recent famine, one of the suggested relief works was the Sangam project for using the flood water of the Pennair. The head works are at Sangam, near Atmakur, and about thirty miles above the *anicut* at Nellor; and their object is to carry water to tanks and reservoirs for irrigation, by which 94,000 acres would be brought under wet cultivation.

The extension of the irrigation works connected with the Krishna and Pennair, and their tributaries, involves questions which touch the interests of by far the largest part of the arid country recently visited by famine. The complete utilization of all the water within this area would be the cause of a great and beneficial change in the physical aspect of a vast region. Such a change, by following in the footsteps of the ancient rulers of the land, the Kings of Vijiyanagar and Telingana, it is the obvious duty of the English masters of India to effect.

At the recent meeting of the American Association for the advancement of science, Prof. Grote, of Buffalo, described a new enemy of the pine tree which he had observed. During June and July the red and white pine trees show by their pitch exuding that they are attacked by an insect. The wounds usually appear on the main stem below the point where a branch starts. On cutting into the bark, the larva will be found which has caused the injury. The length of the larva when full grown is three-quarters of an inch. It makes furrows by eating on the inner side of the bark, producing bleeding, which sometimes kills the tree, and is always injurious. In July the worm spins a whitish gray cocoon within the exuding pitch, and the moth comes forth in 10 or 14 days. It has been found in the Scotch, Austrian, and Russian pine as well as in our native varieties, and seems likely to prove a formidable enemy to the cultivated pine in general. The only remedy yet devised is to apply the knife and cut out the larva.

MOMENTUM AND VIS VIVA.

By J. J. SKINNER, C. E., Ph. D.

Written for Van Nostrand's Magazine.

In the last number of this Magazine Prof. De Volson Wood makes some comments on my previous series of articles under the above title, which seem to require some examination by me. At the top of page 34 he gives the equation

$$F = Mf,$$

and says that I propose to call the second member of this equation *tend*. This is a mistake. I simply proposed to use the word *tend* to denote *the* $\frac{1}{32.1912}$th *part of a pound pressure*, which is not by any means the same thing as the second member of the above equation.

Prof. Wood objects to the introduction of three more *abstract terms*. To which I reply that if the words *pound* and *ounce* are abstract terms, then the words *matt* and *tend* as I proposed to use them may be abstract terms, and not otherwise. Prof. Wood then quotes from me as follows: "As to practical convenience there may sometimes be advantage in using this unit of force." He adds, for himself, "Now I remark that it is absolutely necessary that it (*the* absolute unit) should be used;" concerning which I will say that different nations use different "absolute" units, if they use any; and my illustration as to "practical convenience" had distinct reference to only one of these. No philosopher is *absoluetly* required to use that one, if he prefers the German or the French or any other unit, *absolute* or arbitrary.

On page 35 Prof. Wood inquires, "What are the effects of force?" and answers, "One of its effects is to produce pressure between two bodies; another is to produce motion; another to do work; another to produce energy." May I inquire whether *motion* of masses can be produced without doing *work;* or whether *energy* can be produced without the performance of *work?*

A few lines further on Prof. Wood says of me, "That writer further adds: 'It seems to me that we need in mechanics a name which shall apply to the *exertions of a force during time*, whether this produces apparent motion of masses or not." I discovered too late for correction that the printer had made one error in my sentence, and Prof. Wood's quotation has added another. I wrote, *exertion of force*, instead of *exertions of a force*. Prof. Wood then inquires, "What is meant by *a force* acting during time without producing motion?" But this is not my phrase. My qualifying clause was, "whether this produces *apparent* motion of *masses* or not." In this clause I meant simply to provide for such a case as for example the action of gravity on a heavy body apparently held at rest by a support. Prof. Wood wants to know whether mere pressure exerted during time is any thing but pressure. I should be as glad as he would be to get a good answer to this question, but I confess I do not know what the ultimate nature of *pressure* is. For all we know, *pressure* may be the result of impacts of etherial or ultra-etherial atoms. If it were so, the sum of all these actions on a particular mass of gross matter during a particular time, might be regarded as a definite quantity of *toil*, although the mass of gross matter should *apparently* remain at rest and therefore not acquire any *momentum*. If pressure were simply the result of such impacts as suggested, I should also be wrong in saying that a pound pressure did not necessarily involve the idea of motion.

Prof. Wood says he is unable to determine my position, and quotes what he seems to regard as self-contradictory statements. I confess that I said at the outset of my series, "*If* momentum is a *quantity of motion* it certainly cannot be 100 *pounds;*" but as I went on at some length to show that I did not regard momentum as properly a *quantity of motion*, there was nothing illogical in my afterwards maintaining that under a certain condition the proper unit of the product MV is a pound pressure.

Again, Prof. Wood says: "I would infer that Professor Skinner claims that momentum is pounds of pressure." I think no one can properly infer this from my series of articles, without also knowing that I expressly state the condition under which alone this is correct. See p. 132, Vol XVII, 1st col. near foot, *et passim.* And see also foot note, p. 498.

My distinction between *momentum* and *toil*, if both words were to be employed, would be analogous to the distinction between *vis viva*, (or *energy*), and *work*, as explained on page 501 of last volume. I do not think the introduction of new words tends to confusion, if different ideas have been denoted heretofore by a single word whose meaning has had to be made out by the context.

Prof. Wood seems not unwilling to retain the expression *quantity of motion*, and asserts that *quantity of motion* is *momentum;* also on p. 36 he says, "*the unit of momentum will be one pound of mass moving with a velocity of one foot per second.*" But on p. 137, Vol. XVII, I offer against such a conception an argument which seems to me still valid.

In the last lines of p. 36, Prof. Wood says that he understands me to desire to show that *momentum* must always be considered as positive,—that there is no negative momentum. Such an understanding, or misunderstanding, of my desires seems to me strange, in view of the first three lines of p. 237, vol. XVII, and the distinction made on the same page between *arithmetical* and *algebraic* momenta, together with the demonstration that I had given on p. 236 of the fact that the algebraic total of momentum is unchanged by impact, whether the direction of motion is changed or not. There is fallacy or confusion in an argument or two on p. 236, and I took pains to suggest as much on the same page, saying that "we are inevitably led into all sorts of such *absurdities* if we attempt to consider momentum as a quantity of motion;" and I could easily have pointed out just where the fallacy entered, except that I did not think it worth while.

With regard to my expression "an actual increase of momentum by impact, I hope I only need to suggest that I used the word *actual* to mean no more than *arithmetical* as distinguished from *algebraic.* See 4th line, col. 2, p. 237, &c. I do not hold, and have never maintained that by giving contrary algebraic signs to motions of opposite directions an algebraic increase of momentum could result from impact.

There is, however, this that I may say with regard to my illustrations of the change of direction of motions by a fixed spring or by a semi-circular arc, viz., that I do not deny an effect upon the earth by such change of direction; but, since we know nothing whatever about any material point which is at absolute rest, we are constantly obliged to assume points of reference which shall for argument be regarded as fixed, although they may not in reality be so. If the algebraic as well as arithmetical momentum of two masses could, by impact and a subsequent change of direction of one of them by a simple intervention of human intelligence, be increased with reference to a point fixed relatively to the observer, this might be of interest to him although the algebraic sum total of the momentum of the universe should remain unchanged. It may perhaps be a question whether the algebraic sum of the components of all the momenta of the universe resolved parallel to any given line, is not, with reference to a point absolutely fixed, simply zero.

Prof. Wood calls attention to my applying the phrase *potential energy* to the quantity $\frac{1}{2}MV^2$. I know that this energy is usually called *kinetic* and in the offending sentence I might perhaps as well have omitted the word *potential;* but since this energy can be regarded as stored up, or accumulated, by a body, and is not to be exerted for any time, however long, unless some reduction of velocity is produced, it can, in a sense not technical, be regarded as potential.

I believe any one who has attempted to think or write on this general subject will admit that it is a difficult one to treat controversially with perfect freedom from error. In my discussion I can hardly hope to have made no slips, but we, none of us, like to have our work made to appear more unworthy than it really is.

An important discovery of coal is reported to have been made at South Creek, New South Wales.

ON THE CONSTRUCTION AND WORKING OF NARROW-GAUGE AND OTHER SECONDARY RAILWAYS.

By JULES MORANDIERE.

From "Mémoirs de la Société des Ingénieurs civils," translated Abstracts published by the Inst. of Civil Eng.

The object of this Paper is to collect together the statistics and other information relating to the present position of these railways, the extent of which in each country of the world may be seen from the figures in the following table (A):

Name of Country.	Number of Miles.	
	Open to Traffic.	In Construction.
Great Britain	26	—
France	433¾	89¼
Algiers	20½	155½
Belgium	77	—
Norway	192½	—
Sweden	163	—
Russia	208¼	—
Austro-Hungary	52¾	18¾
Prussia	20	—
Italy	7½	—
Island of Sardinia	18	—
Switzerland	22	—
Greece	5½	—
Portugal	—	—
India	820½	1,902
Australia	328	—
New Zealand	244	—
Cape of Good Hope	67	—
Canadian Dominion	457	373
United States	2,040	7,552
Central America	37¼	155
Venezuela	—	—
Peru	17¼	—
Chili	118	—
Bolivia	—	155
Brazil	20	411
Havana	—	—
Java	34	—

The above table shows that, during the last few years, the number of narrow-gauge lines has increased enormously. The writer is not of opinion that their adoption in France would be advisable, excepting under special local conditions, and thinks that it would be preferable to retain the ordinary gauge of 4 feet 8½ inches even for the railways of secondary importance, in order to avoid changes of carriages and wagons, but the narrow gauge is advantageous in new countries where the object is to obtain the greatest possible extension of railway communication with a limited amount of capital, and for local purposes, especially for the carriage of mineral or agricultural produce, provided that it has not to be subsequently transferred to the wagons of another railway.

A second table shows the names, lengths, gauge, weight of rails, cost of construction, &c., of the principal narrow-gauge railways in the different countries of the world.

In the following short description of some of these, the four first are laid upon or parallel with turnpike roads:

Lagny to the Stone Quarries of Neufmoutiers and to *Montcerf* (France). This railway, 9¼ miles in length, was originally constructed for the carriage of stone only, but afterwards, at the solicitation of the neighboring towns, passenger carriages were added. It is only seventeen miles from Paris, and is frequently visited from thence as a specimem narrow-gauge line. It runs parallel to the high-road, from which it is separated by a ditch, and this allowed of much economy in the purchase of land. The gauge is 3 feet 3⅜ inches (1 meter) between the rails; weight of rails thirty-two pounds per yard; sleepers two feet six inches apart; width of banks at formation-level nine feet ten inches. The locomotives have six coupled wheels, and weigh, including water and coal, from thirteen to fourteen tons. There are carriages for first, second, and third class passengers, the first with eighteen and the third with twenty-four seats. An extension of five miles to Montcerf remains to be finished.

Turin to Rivoli (Italy).—This railway, 7½ miles in length, runs along the side of a broad avenue, and connects Turin with the suburbs. The maximum gradient is 1 in 60; the gauge is two feet 11.4 inches (0.90 meter) between the rails; the weight of the rails is forty-three pounds per yard; the sleepers are two feet eight inches apart. The locomo-

tives have four coupled wheels, and weigh about eleven tons. The carriages are very small, and only allow of three passengers being seated abreast. The average speed of the trains is 12½ miles per hour.

Lausanne to Echallens (Switzerland).—This railway, ten miles long, is only built on the turnpike-road for a certain distance, and for that length it has been necessary to widen the road by about six feet in order to leave a clear eighteen feet for the ordinary traffic. There is one curve of sixty-six yards radius and nine of 110 yards; the maximum gradient is 1 in 25 for a distance of 660 yards. The gauge is three feet 3⅜ inches (1 meter). The weight of the rails is fifty-eight pounds to the yard. The stations consist of two small rooms connected by a third, which is open on the side facing the railway, and they are constructed of wood. There are two locomotives, one weighing fourteen, the other eight tons. The speed of the trains is 12½ miles per hour.

The Broelthal railway (Rhenish Prussia) is twenty miles in length, of which fourteen miles are on a road and six miles in the ordinary way through fields, &c. It was constructed at a total expense of £1,722 per mile; viz., for permanent way, &c., £18,140; for a bridge over the river Sieg £3,540; for stations £5,765; for rolling stock £4,900; for stores, &c. £2,105; making a total of £34,450. A local subvention of £9,000 was granted to the company. The gauge is two feet seven inches.

The Rochebelle railway, with a length of one mile 290 yards, carries coals exclusively. The maximum gradient is 1 in 56 for 534 yards; the minimum radius of curve is sixty-six yards. Very small locomotives are used, which draw twenty empty wagons up the incline; the average speed is 8½ miles per hour. In 1873, 60,000 tons of coals were carried at an average cost of 5½d. per ton per mile.

The Mokta-el-Hadid railway (Algeria) is 20½ miles in length, and connects the mines of that name with the seaport of Bona. The gauge is 3 feet 3¼ inches; minimum radius of curves 257 yards; maximum gradient 1 in 117. The original iron rails have been taken up, and the line has been relaid with steel rails weighing forty pounds per yard. The sleepers are two feet six inches apart. Cost of permanent way per yard with iron rails £1 5s.; ditto with steel rails £2. The weight of the locomotives (with six coupled wheels) is sixteen tons (empty), that of the wooden wagons 1 ton 18 cwt.; that of the iron wagons 2 tons 2 cwt. The rolling stock consists of six locomotives and two hundred and twenty-five wagons. Seven trains, each of forty wagons, run daily in each direction; average speed 10½ miles per hour.

In Norway six narrow-gauge railways, with a total length of 192½ miles, have been opened for traffic, and a further 200 miles are in construction. They are all passenger lines, and have been built by the State. The rails weigh from thirty-five to forty pounds per yard. The gauge is three feet six inches; the minimum radius of curves is 200 yards; the maximum gradient is 1 in 45; the average speed is 12½ to 15½ miles per hour, including stoppages, that of express trains is 18½ miles per hour. In 1871 the average gross receipts on 144 miles were at the rate of £218 per mile per annum, and the net receipts £45 per mile.

In Sweden fifteen short lines, making a total of 480 miles of narrow-gauge railways, have been built by private companies, and 150 miles are in construction. Five different gauges have been adopted, varying from two feet seven inches to four feet. These lines have cost from £1,900 to £3,200 per mile; the average speed is under fifteen miles per hour. The rails weigh twenty to forty-five pounds per yard.

The system has been adopted in Sweden of building second-class railways with the ordinary gauge of 4 feet 8½ inches, and with light rails weighing from forty to sixty pounds per yard. About 590 miles of such railways have been opened to traffic, and 1,140 miles are in construction. They answer very well. Their average cost, including rolling stock, is £6,400 per mile.

In Russia the railway from *Vierhovie* to *Livny* (38½ miles) and that from *Novgorod* to *Tschudowo* (45½ miles) have been constructed with two feet six inches gauge. The first has a viaduct over the river Linbovsha, which is 420 feet long, and the gradients rising from this point are 1 in 8 for 7,000 yards in

one direction, and for 9,590 yards in the other. The weight of the rails is forty-five pounds. The rolling stock of the Livny line consists of two ordinary locomotives, five Fairlie engines, seventeen passenger carriages, and two hundred and sixty-six goods wagons. The same gauge of two feet six inches has been used on 125 miles of other lines in Russia. They have cost on the average (including rolling stock) at the rate of £6,000 per mile.

In Austro-Hungary gauges of three feet 1½ inch, 3 feet 3⅜ inches, and 3 feet 7½ inches have been used on six short lines.

In Switzerland the meter gauge has been adopted on three short lines, and the 2-foot 5½-inch gauge on a fourth.

In British India 820 miles have been opened to traffic, and 1,900 miles remain to be finished. The gauge is 3 feet 3⅜ inches; the weight of rails forty pounds to the yard. Six-wheel locomotives, weighing from twenty to twenty-two tons, are used. The passenger carriages are made with double sides, and at about one foot above the ordinary roof they have a second roof, which projects considerably beyond the lower one to keep off the sun's rays. The first-class carriages are comfortable saloons fitted for seven passengers, and with sleeping accommodation for five. At one end is a retiring room, with washing and toilet arrangements, and at the other a compartment for servants. The cost per mile has varied from £1,088 to £11,392, but the average (including rolling stock) appears to have been about £6,000 per mile.

In Queensland (Australia) 300 miles of railway, with a gauge of three feet six inches, have been opened to traffic. The weight of the rails is forty pounds to the yard. These lines have cost from £4,600 to £11,500 per mile.

In South Australia twenty-eight miles, with 3-foot 6-inch gauge, have been constructed. The weight of the rails is forty pounds.

In New Zealand, the same 3-foot 7½-inch guage has been adopted on 244 miles.

At the Cape of Good Hope sixty-seven miles have been constructed, also with a 3-foot 6-inch gauge. Several hundred miles are in course of construction.

In the Dominion of Canada the same guage has been adopted on 457 miles of completed railway, whilst a further 373 miles are in course of construction. The average cost per mile of the Toronto-Bruce and Toronto-Nipissing lines, including rolling stock, is stated to have been £3,008; only £448 and £608 per mile on the two lines respectively being charged as expended on rolling stock.

United States of America. A separate table is attached to the original, giving the names and length of sixty-four narrow-gauge railways in the United States, of which 2,039½ miles were, on the 1st of July, 1874, open to traffic, and 7,552 miles in construction. The most important of these is the Denver and Rio Grand railway, of which at that date 161½ miles were finished, and 870 miles in construction. The gauge is three feet; the weight of the rails thirty-three pounds. The first seventy-five miles cost at the rate of £3,000 per mile, but the remainder, being over rougher ground, has cost £4,000 per mile. In 1873, on 118 miles, the gross receipts averaged £13 per mile per week; the working expenses £6, and the net receipts £7. The rolling stock resembles that on other American ordinary guage railways; but some Fairlie engines with twelve wheels, and weighing twenty-six tons, have been adopted. On the Arkansas Central and some other American lines the gauge is three feet six inches.

In Costa Rica (Central America) a 3-foot 6-inch guage has been used on a line now in construction from the capital, San José, to the Port on the Atlantic. The rails weigh 42 pounds to the yard; 37¼ miles are in traffic, and 155¼ in construction.

In Peru a 2-foot 6-inch gauge has been adopted on the Patillos line, the object of which is to carry nitrate of soda from the interior to the coast. The weight of the rails is thirty-five pounds. This line has some steep gradients of one in twenty-eight, and Fairlie engines, weighing twenty-six tons, are used.

It is stated that the latter run on ten other railways. It results from the data supplied in this Paper that the constructors of narrow-gauge railways have adopted almost every conceivable variety of guage between 1 foot 6 inches and 4 feet. The following twenty varieties

will be found in Table C, viz: 1 foot 6 inches, 1 foot 11½ inches, 2 feet 3½ inches, 2 feet 5½ inches, 2 feet 6 inches, 2 feet 6½ inches, 2 feet 7 inches, 2 feet 7½ inches, 2 feet 11½ inches, 3 feet, 3 feet 1½ inch, 3 feet 1¾ inch, 3 feet 3 inches, 3 feet 3½ inches, 3 feet 6 inches, 3 feet 7½ inches, 3 feet 7½ inches, 3 feet 10½ inches, 3 feet 11½ inches, 4 feet.

Some information is supplied in reference to tramways, especially those in Belgium, and the Author recommends particularly the mode of laying and the description of rail employed on the Liege tramways. Also a large amount of further interesting information on the subject of economical railways generally is contained in the Paper, which the limits of an abstract will not allow of being reproduced.

CHAIN TOWING ON THE ELBE.

Translated from "Revue Industrielle."

THROUGHOUT the navigable portion of the Elbe, from Aussig in Bohemia to Hambourg, the system of chain towing is employed.

The ordinary steam-tugs being unable to compete with the railway, and the towage on the Seine and other French rivers having yielded such good results, M. Nobiling made a special examination of the systems already at work. He found on the Seine a towing system, having a fifty horse power engine hauling a dozen barges, carrying a total load of 3,000 tons at a velocity of 3,200 meters (2 miles) per hour against a current having a velocity of 4000 meters (about 2½ miles) per hour. The system furthermore presents the advantage of producing no waves, an advantage that extends to the maintenance of landings, bath-rooms, rafts, etc.

The Navigation Co. of Hambourg-Magdebourg, having obtained a *concession* for thirty years, selected for their preliminary experiments, a portion of the river between Buckau and Neustadt, about 4,800 meters in length, and where the steam tugs worked with difficulty when the river was high. The chain was established between these two cities, and a flat-bottomed tow-boat, constructed in the work-shop of the Company began a regular service in August, 1866. It was attended with complete success.

The chain was then extended to Ferchland, 48 kilometers below Magdebourg, at a cost of 254,625 francs for the chain, and 264,375 francs for three tow-boats; a total of 519,000 francs ($103,800). This proved so remunerative that the Company decided to extend their work to Hamburg, in order to secure the traffic which amounts annually to 300,000 tons. The remaining 158 kilometers were completed in 1874 at a cost of 3,250,000 francs ($650,000) including a set of ten tows in service.

From 1869 to 1871, 320 kilometers of chain had been established in the upper portion of the Elbe, not including 22.4 kilometers in the Saale, one of the branches of the Elbe.

The total length now of chain in this system is 672 kilometers (418 miles) and the number of tows is 25.

It is estimated that in the old tug-boat system there was a loss of sixty to seventy per cent. of the useful effect, because the force was exerted against a mobile fluid, a loss which is avoided in using the chain.

Where the current is feeble, a single winding drum of large size is sufficient, the chain being held against the drum by two rollers on the lower side; and the chain is further prevented from slipping by a notched groove in the drum which receives the links of the chain. Against rapid currents, or in case of heavy towage two drums are necessary, and four or five turns of the chain about each.

The duration of a chain on the Elbe is about twelve years. The wear is experienced in slipping while passing from one drum to the other. The most frequent breakages have occurred when winding the chain for the first time.

In boats furnished with two drums, the latter are placed centrally, one behind

the other. When there is only one drum, it is upon the side.

It is estimated that this system of towage utilizes eighty to eighty-five per cent. of the power of the machines, and that the consumption of coal is only one-fifth of that of the side wheel tow-boats.

The buoyed chain in the Elbe is an English navy chain of the best quality and of ordinary dimensions; the length of the link being $4\frac{1}{2}$ times the diameter of the iron; which for the Buckau-Wittemberg section is 22 millimeters, and weighs 11 kilos. per meter (21 + lbs. per yard). From Wittemberg to Hambourg, the diameter is 25 millimeters, and the weight is 15 kilogrammes per meter. The chain employed on the Seine has a diameter of only 16 millimeters, a size that would not serve against the swifter currents of the Elbe.

The two extremities of the tow-boats are alike, and are equally furnished with a rudder. The steering wheels are both in the middle of the boat, so that a single helmsman performs the steering, and is conveniently near the machine-room at the same time.

The dimensions adopted are as follows: length 42 to $45\frac{1}{2}$ meters; breadth 7 to $7\frac{4}{10}$ meters; depth at center $2\frac{1}{10}$ meters; draft $\frac{45}{100}$ meter. Boats drawing less water do not give so good results. They are constructed mostly of boiler plate iron, having a thickness of $6\frac{1}{2}$ millimeters for the sides and 12 millimeters for the bottom. Latterly, pine of 100 millimeters (4 inches) has been employed for the flooring, and for the bottom oak planking of the same thickness. It is found that wood suffers less than iron when it encounters a pebbly bottom.

Upon the Upper Elbe the tow boats are furnished with two boilers, while on the lower Elbe they have but one. The boilers are horizontal and are designed to furnish 60 to 80 horse-power working at a variable pressure of 5 to 7 atmospheres.

The power is transmitted to the drums by a system of gear wheels. The drums admit of five turns of the chain and a brake. The diameter of each drum is $1\frac{1}{10}$ meters, and as the velocity is about 60 revolutions per minute, 210 meters of chain per minute pass over the drum when descending, and about 114 meters when ascending the current, giving theoretical velocities respectively of 12600 and 6840 meters per hour, but which are really 9600 and 4800 meters.

Sometimes as many as thirty pinnaces have been towed at once upon the upper Elbe; the mean number is from four to eight barges. The toll paid is according to tonnage and distance.

There are twenty-five stations on the upper Elbe and twenty-four on the lower. Between certain stations where the towage is difficult the tolls are somewhat increased.

The section between Buckau and Newstadt pays good dividends. Three thousand boats carrying a total of 150,000 tons have passed over this section annually, and have afforded a revenue of 7 or 8 per cent on the original capital.

Upon the lower Elbe the results have not been so favorable, in consequence of an increase of the rates.

The number of days of service of the system has been during four years:

In 1872	....	303 days.
1873	....	340 "
1874	....	293 "
1875	....	259 "

being an average of 300 days.

The distance between Magdebourg and Dresden is accomplished in 72 hours by the chain, but requires 120 hours by the tug-boats.

The boats carrying merchandise are of three classes according to tonnage; they are of 150, 300 and 400 tons burden. The larger ones are the more economical, as is proven by the following figures which exhibit the cost per ton to the company of the transportation both ways between Hambourg and Dresden:

	150 tons	300	400
Going up.....	14.37 f.	12.24 f.	11.66 f.
Going down ..	5.47 f.	4.01 f.	3.49 f.

F. Perrier has, according to the *Comptes Rendus*, made a comparative study of day and night observations, from which he concludes "that azimuthal observations by night possess a degree of precision at least equal, if not superior, to that of observations by day." He will make a special study of the effects produced upon the azimuthal measures by the torsion of the wooden signals under the direct action of the sun's rays.

THE STATUS AND PROSPECTS OF ENGINEERS.

By GRAHAM SMITH, A.I.C.E.

GENTLEMEN,—It is now two years since you conferred upon me the honor of allowing me to address you as your president. You will remember that on that occasion my remarks were confined to the importance of societies established on a basis such as ours. This evening I purpose touching upon a somewhat wider subject, and one on which a variety of opinions and notions exists, namely, "The Status and Prospects of Engineers."

A few lines from a "leader" which appeared in the *Scotsman* convey some idea of the public opinion concerning our profession. They are as follows :—"The most observant of country readers will have often noticed that whenever any particularly magnificent or rather astonishing announcement is made, such as a proposal to bore a hole through the earth, or swing the moon round in time to get a shower for the early turnips, the proposer of the said scheme always signs himself C. E. That symbol is the badge of perhaps the most remarkable class of men on the face of the earth. Their progress, like that of the Prussians, has been gradual, yet ceaseless, and has been too little attended to by their neighbors. From small beginnings they have grown so that nothing is too big for them to handle. We may premise that they are a most respectable class of men. They generally sport white vests with adequate coat and continuations, and have an aristocratic look about them. At the same time it is aristocracy tempered with science. They bear themselves with a certain conscious dignity, as becomes men who have taken more liberties with our planet than their neighbors dare to do. In fact, a noble pride, made nobler by humility, is the chief ethical characteristic of the civil engineer. He has a right to be proud. Look at what he has done—what railways he has executed; what harbors he has built; what canals he has dug out; what big ships he has launched broadside foremost, in defiance of all the old women and common sense of the community!"

* Address delivered before the Liverpool Engineering Society.

It is true that the scientific progress of the profession has been gradual and ceaseless, still the ancients executed works of even greater magnitude than those undertaken at the present day. Lake Mœris was a vast reservoir constructed to impound the flood waters of the Nile, which were afterwards used for irrigation. It had an area of 150 square miles, and the wall or dam which retained these waters was sixty yards wide, thirty feet high, and its site may be traced for a distance of thirteen miles. The pyramids of Gizeh, constructed 5000 years back, and the causeways of solid granite which were laid down to facilitate the transport of stones, often hundreds of tons in weight, were works of vast magnitude. The causeways no longer exist, but Herodotus, who saw them, considered them even greater works than the pyramids themselves. The masonry of these works, and the lifting and transport of the huge blocks, could only have been performed by large armies of men, directed by competent leaders who must have possessed a considerable knowledge of the properties of materials, and must have had a true sense of the simple elements of mechanics.

The profession is undoubtedly of ancient lineage. Tubal Cain was a worker in metals. Dr. Lepsius states that a Royal High Architect of the Dynasty of the Psammetici has sculptured his pedigree of twenty-three generations on the rock of one of the most ancient quarries of Egypt. George Smith, the great explorer of the ancient East, found by an inscription that the title of "Master of Works" existed in Assyria 2500 years back. The remains of canals, aqueducts, reservoirs, and other works are to be found in Egypt, India, China, and, in fact, all over the world, clearly denoting that the ancients possessed men answering to the description and filling the position which the engineer of the present day occupies. The engineer of the ancients was a man of distinction, appreciated and favored by kings and rulers. His works were

the other. When there is only one drum, it is upon the side.

It is estimated that this system of towage utilizes eighty to eighty-five per cent. of the power of the machines, and that the consumption of coal is only one-fifth of that of the side wheel tow-boats.

The buoyed chain in the Elbe is an English navy chain of the best quality and of ordinary dimensions; the length of the link being $4\frac{1}{2}$ times the diameter of the iron; which for the Buckau-Wittemberg section is 22 millimeters, and weighs 11 kilos. per meter (21 + lbs. per yard). From Wittemberg to Hambourg, the diameter is 25 millimeters, and the weight is 15 kilogrammes per meter. The chain employed on the Seine has a diameter of only 16 millimeters, a size that would not serve against the swifter currents of the Elbe.

The two extremities of the tow-boats are alike, and are equally furnished with a rudder. The steering wheels are both in the middle of the boat, so that a single helmsman performs the steering, and is conveniently near the machine-room at the same time.

The dimensions adopted are as follows: length 42 to $45\frac{1}{2}$ meters; breadth 7 to $7\frac{4}{10}$ meters; depth at center $2\frac{1}{10}$ meters; draft $\frac{45}{100}$ meter. Boats drawing less water do not give so good results. They are constructed mostly of boiler plate iron, having a thickness of $6\frac{1}{2}$ millimeters for the sides and 12 millimeters for the bottom. Latterly, pine of 100 millimeters (4 inches) has been employed for the flooring, and for the bottom oak planking of the same thickness. It is found that wood suffers less than iron when it encounters a pebbly bottom.

Upon the Upper Elbe the tow boats are furnished with two boilers, while on the lower Elbe they have but one. The boilers are horizontal and are designed to furnish 60 to 80 horse-power working at a variable pressure of 5 to 7 atmospheres.

The power is transmitted to the drums by a system of gear wheels. The drums admit of five turns of the chain and a brake. The diameter of each drum is $1\frac{1}{10}$ meters, and as the velocity is about 60 revolutions per minute, 210 meters of chain per minute pass over the drum when descending, and about 114 meters when ascending the current, giving theoretical velocities respectively of 12600 and 6840 meters per hour, but which are really 9600 and 4800 meters.

Sometimes as many as thirty pinnaces have been towed at once upon the upper Elbe; the mean number is from four to eight barges. The toll paid is according to tonnage and distance.

There are twenty-five stations on the upper Elbe and twenty-four on the lower. Between certain stations where the towage is difficult the tolls are somewhat increased.

The section between Buckau and Newstadt pays good dividends. Three thousand boats carrying a total of 150,000 tons have passed over this section annually, and have afforded a revenue of 7 or 8 per cent on the original capital.

Upon the lower Elbe the results have not been so favorable, in consequence of an increase of the rates.

The number of days of service of the system has been during four years:

In 1872	....	303 days.
1873	....	340 "
1874	....	293 "
1875	....	259 "

being an average of 300 days.

The distance between Magdebourg and Dresden is accomplished in 72 hours by the chain, but requires 120 hours by the tug-boats.

The boats carrying merchandise are of three classes according to tonnage; they are of 150, 300 and 400 tons burden. The larger ones are the more economical, as is proven by the following figures which exhibit the cost per ton to the company of the transportation both ways between Hambourg and Dresden:

	150 tons	300	400
Going up.....	14.37 f.	12.24 f.	11.66 f.
Going down ..	5.47 f.	4.01 f.	3.49 f.

F. PERRIER has, according to the *Comptes Rendus*, made a comparative study of day and night observations, from which he concludes "that azimuthal observations by night possess a degree of precision at least equal, if not superior, to that of observations by day." He will make a special study of the effects produced upon the azimuthal measures by the torsion of the wooden signals under the direct action of the sun's rays.

THE STATUS AND PROSPECTS OF ENGINEERS.

By GRAHAM SMITH, A.I.C.E.

Gentlemen,—It is now two years since you conferred upon me the honor of allowing me to address you as your president. You will remember that on that occasion my remarks were confined to the importance of societies established on a basis such as ours. This evening I purpose touching upon a somewhat wider subject, and one on which a variety of opinions and notions exists, namely, "The Status and Prospects of Engineers."

A few lines from a "leader" which appeared in the *Scotsman* convey some idea of the public opinion concerning our profession. They are as follows :—"The most observant of country readers will have often noticed that whenever any particularly magnificent or rather astonishing announcement is made, such as a proposal to bore a hole through the earth, or swing the moon round in time to get a shower for the early turnips, the proposer of the said scheme always signs himself C. E. That symbol is the badge of perhaps the most remarkable class of men on the face of the earth. Their progress, like that of the Prussians, has been gradual, yet ceaseless, and has been too little attended to by their neighbors. From small beginnings they have grown so that nothing is too big for them to handle. We may premise that they are a most respectable class of men. They generally sport white vests with adequate coat and continuations, and have an aristocratic look about them. At the same time it is aristocracy tempered with science. They bear themselves with a certain conscious dignity, as becomes men who have taken more liberties with our planet than their neighbors dare to do. In fact, a noble pride, made nobler by humility, is the chief ethical characteristic of the civil engineer. He has a right to be proud. Look at what he has done—what railways he has executed; what harbors he has built; what canals he has dug out; what big ships he has launched broadside foremost, in defiance of all the old women and common sense of the community!"

It is true that the scientific progress of the profession has been gradual and ceaseless, still the ancients executed works of even greater magnitude than those undertaken at the present day. Lake Mœris was a vast reservoir constructed to impound the flood waters of the Nile, which were afterwards used for irrigation. It had an area of 150 square miles, and the wall or dam which retained these waters was sixty yards wide, thirty feet high, and its site may be traced for a distance of thirteen miles. The pyramids of Gizeh, constructed 5000 years back, and the causeways of solid granite which were laid down to facilitate the transport of stones, often hundreds of tons in weight, were works of vast magnitude. The causeways no longer exist, but Herodotus, who saw them, considered them even greater works than the pyramids themselves. The masonry of these works, and the lifting and transport of the huge blocks, could only have been performed by large armies of men, directed by competent leaders who must have possessed a considerable knowledge of the properties of materials, and must have had a true sense of the simple elements of mechanics.

The profession is undoubtedly of ancient lineage. Tubal Cain was a worker in metals. Dr. Lepsius states that a Royal High Architect of the Dynasty of the Psammetici has sculptured his pedigree of twenty-three generations on the rock of one of the most ancient quarries of Egypt. George Smith, the great explorer of the ancient East, found by an inscription that the title of "Master of Works" existed in Assyria 2500 years back. The remains of canals, aqueducts, reservoirs, and other works are to be found in Egypt, India, China, and, in fact, all over the world, clearly denoting that the ancients possessed men answering to the description and filling the position which the engineer of the present day occupies. The engineer of the ancients was a man of distinction, appreciated and favored by kings and rulers. His works were

* Address delivered before the Liverpool Engineering Society.

held in estimation, for among the titles of the God Vul were those of "Lord of Canals" and "The Establisher of Irrigation Works."

At the present time the leaders of the engineering profession are totally unrecognized by the British Government. On state occasions the merest subaltern in the army takes precedence of engineers, whose energy, ability, and perseverance have been, both directly and indirectly, to no small extent instrumental in placing Great Britain on the high pinnacle upon which she now rests. Patronage has a tendency to enfeeble its recipients; and even were this not the case, engineers are able to dispense with it. Bearing in mind Wordsworth's ideal of manly dependence and manly independence, they steer their own course and assume their own position. All that the profession in general requires is a fair field and no favor, which our Government does not see fit to accord to it in a country like India.

Although titles may be showered on corporate dignitaries and the members of other professions, they are sparsely distributed in that of the engineer, but, excepting as a means of rendering him of increased usefulness, he ought to care little about them. By his own work he may gain more distinction and honor among the inhabitants of the civilized world than it is in the power of all the crowned heads of Europe to bestow. There is no royal road to eminence for the engineer; his honors are alone to be attained by hard work, and cannot be bought at any price. He is yet entitled to have high aspirations as a benefactor of men, among whom he must occupy an enviable position, for his profession implies the possession of the art of controlling the force of the winds and falling waters, so that they may be made to grind corn and weave cloth—to feed and clothe man; the making and perfecting of machinery for the purposes of cultivation, and the construction of roads, railways, canals, and bridges for the collection and distribution of the products of the earth; the construction of docks and harbors for the convenience and safety of ships bringing raw materials from foreign lands to provide employment for millions, and carrying back the products of vast industries; the ventilation, warming, and draining of the habitations of these people, and the bringing of the pure water of the mountain rill to their very feet; the inventing and perfecting of machinery with which to mine into the bowels of the earth for hidden treasures, and render them convenient for the uses and wants of mankind; and the performing of a multitude of other useful offices much too great to now mention. Thus it is evident that the civilization, welfare, and advancement of nations are to no small extent dependent on the work of the engineer.

It is asked on all sides, what are the prospects of gaining distinction in this vast field of usefulness? In the first place, a man must have ability and training to do his work; and in the second place, he must love it, or the disappointments and hardships which he will have to encounter during the early part of his professional life will possibly cause him to under-estimate his capacities, and render him wanting in self-reliance and decision of character. Nevertheless trials are almost necessary to the proper development of an engineer, just as iron must pass through the fire before it is converted into steel. It is not in the power of every man who enters the profession to become distinguished. Still, if a man of average ability starts in life with a fixed purpose and works determinedly with his whole heart, hands, and brain, asks few favors, and relies on his own labors, he has good prospects of attaining that object.

It is undesirable to have firmness of purpose without sound judgment. In early life it is always better, therefore, to lean to some extent on the judgment of men who are known and tried, and to work cautiously on one's own ideas until the judgment has been educated and its correctness has been repeatedly tested. An engineer having proved himself by self-examination and repeated trial to have a tolerably sound judgment, should then ask advice of those only who are so far interested in his welfare as to trouble themselves sufficiently with his affairs to be in a position to give judicious counsel. Having, with the aid of such few friends, matured measures, they must be fearlessly carried out under the banner bearing the device "I dare do all that may become a man."

He who carries through whatever he undertakes is on the road to making a reputation. Yet it is necessary to be careful, not to promise too much, and to ascertain that the elements of success attend the proposed work, before embarking one's energies in the undertaking.

The friends of the merest tyro in engineering will tell you that he is possessed of talents and genius; and when these are combined with vigor, what may not an engineer achieve in his life? It has been said—"He who in a given time can produce more than many others has vigor; he who can produce more and better has talents; he who can produce what none else can has genius." Now, so long as the major part of the members of the engineering profession possess these qualities, it is safe from falling into the condition of the land portrayed by Goldsmith

> "To hastening ills a prey,
> Where wealth accumulates, and men decay."

The profession is quite safe for the present from the baneful influences of riches, and, so long as the supply of men lasts who are competent and willing to do professional routine work for the present scale of remuneration, it can never be looked upon as a means of amassing wealth. Notwithstanding the railway mania, and the great demand for machinery and engineering work during the past half-century, few men have made large fortunes by engineering pure and simple.

Instances are not wanting where young engineers in charge of works have received smaller salaries than the foremen masons and other craftsmen working under their direction. Public bodies seem to form the lowest estimate of the value of engineers. This is possibly owing to the fact that men forming such boards seldom have any knowledge of engineering, and, as the money for the works does not come out of their pockets, they fail to appreciate the false economy of employing incompetent men.

It is not long since the Commissioners for a somewhat important harbor and port required the services of an engineer, and issued a printed memorandum on the duties they expected him to perform. He was to carry out the construction of a concrete block breakwater, the building of a sea wall, and the designing and execution of such other works as were required from time to time; and to have charge of the repairs of a lighthouse, ferry, piers, &c., and the supervision of the men employed on all works. He ought to have a sound knowledge of the commercial value of materials and labor, as the works were to be carried out without the aid of contractors. The making of marine surveys, the taking of periodical soundings in the bay, and the dredging and dredge plant, were also to be placed in his hands. In addition to his professional duties he was to act as harbor master, accountant, and secretary to the Commissioners. They required a surety of £500, and, after reserving the right of separating the offices, named the enormous salary of £350 per annum for the combined appointments.

In this instance the Commissioners merely followed the doubtful lead set by many Bodies responsible for the carrying out of operations involving the expenditure of thousands, who do not trouble themselves to ascertain the market value of men capable of properly undertaking their work. It is, however, pleasing to be aware that, even in these dull times, a commodity of this nature commands three or even four times the figure set upon it by the Commissioners in question.

Punch's advice to those about to marry, "Don't," aptly applies to those purposing to enter the profession as a money-making business. This does not imply that a livelihood cannot be obtained by hard work in this as in other professions. Any one with ability, and a mind above mere money grubbing, may find work to suit his inclinations either in the office, field, study, works, or even in the wilds of unexplored countries. While in the rank and file of the profession he will be very poorly paid, considering the amount expended on his technical education and the social position he is expected to occupy. He cannot hope to leave the ranks until he is nearly thirty years of age. Even before that he may possibly secure a salary of £300 or £400 per annum, but on entering the profession and for no short period of his early life he can only calculate on earning a few guineas per week.

At the age of twenty-eight or thirty superior berths of various descriptions open to him; if he is possessed of mechanical talents he may obtain an appointment as manager of works, or become a partner in an established firm. Those who prefer to go abroad may take charge of surveying expeditions, and the carrying out of foreign work for contractors and others. Home-birds may content themselves with municipal engineering and offices under engineers-in-chief to Public Bodies

Although there are many public appointments in which the remuneration exceeds £1000, and a few in England even reaching £5000 per annum, the man who purposes working under others all his lifetime can, only in exceptional instances, expect to make more than £700 or £800 per annum during any portion of his career, and it is not probable that he will reach that figure before he has attained an advanced age. In America, Japan, India, and other foreign countries, matters follow much the same course; and although the salaries paid may be nominally larger, the purchasing value of money is reduced as the cost of the necessaries of life are enhanced.

It is still satisfactory to know that, although the scale of remuneration is small, a young engineer, when thoroughly master of the details and routine of his profession, may at all times rely upon obtaining work of one kind or other. He is thus placed in a position of independence when compared with young men who enter the mercantile world, and if he be scrupulously careful he may be able to save a sufficient sum of money to defray incidental expenses by the time he is competent to undertake a private practice.

The difficulties facing a young man entering upon a private practice are great. The sums of money involved in engineering undertakings are so large that people are rarely disposed to entrust them to an untried man, although he may have gained some reputation, and rather prefer placing their works in the hands of established men. Then, again, young men are, as a rule, put down by a majority of persons as being entirely devoid of wisdom; cousultation fees are not likely, therefore, to pour in at a very rapid rate. In the witness box the most able evidence of a young engineer is weakened simply by the opposition counsel asking the witness his age. After an engineer has to some extent established himself, he will still have to encounter many difficulties not experienced by other professions. A barrister, doctor, or lawyer has only to conduct his early work well, and it forms the nucleus of a more extended practice. An engineer may conduct his work in the most able and skillful manner, but on its completion he receives the thanks of his friends, and says adieu to them and the work, and it will probably be some time before his clients require a similar undertaking carried out.

This by no means implies that he should have a contempt for other people's capital, or carry his work through in a careless or haphazard manner. His reputation as an engineer entirely depends upon his work, and his success in life on his reputation.

It requires the labor of years to make a reputation, and the man essaying to do it may often be in a very sorry plight. If he has integrity, ability, and perseverance he will find a few friends to assist him in the unpropitious times of his youth; and then it is to be remembered that a well-balanced mind can accomodate itself to the vicissitudes of fortune.

An engineer need never be ashamed of poverty, and should be actuated by higher motives than mere money getting. The love of his profession, if he possess it, will go far to sustain him through trying circumstances, and should occupy in his mind the position attributed to the love of knowledge by Sydney Smith when he said "I solemnly declare that but for the love of knowledge I should consider the life of the merest hedger and ditcher as preferable to that of the greatest and richest man here present; for the fire of our minds is like the fire which the Persians burn in the mountains: it flames night and day, and is immortal and not to be quenched—upon something it must act and feed—upon the pure spirit of knowledge, or upon the foul dregs of polluting passions."

The gigantic works executed by the ancients have already been referred to, and whilst admitting their magnitude they must by no means be considered as exhibiting superior skill to that existing

at the present day. In the works of the Suez Canal and Mont Cenis Tunnel, nature's barriers to national intercommunication have been removed by the skill of men now living. The blowing up of the mass of rocks in the "Hell Gate"; the deepening of the Mississippi mouths; the construction of the East River Bridge, New York; and, lastly, in our own country the Tay Bridge and the Metropolitan Railway, carrying annually its millions, and adding to the health and comfort of the inhabitants of one of the largest cities in the world, are all instances of the scientific progress of our profession, and will long remain as monuments to immortalize such names as Lesseps, Sommeiller, Grattoni, Eads, and Fowler.

Equally magnificent and useful works still remain to be accomplished. The great continents of North and South America have yet to be separated by a canal across the Isthmus of Panama. India has to be irrigated; the English Channel to be tunneled. China, Japan, South America, Africa, Persia, and Russia have yet to be opened up by the work of the engineer. These and other undertakings provide amply sufficient fields for the employment of our energies for an indefinite period; and if the abilities bestowed by a Supreme Being be directed to the accomplishment of such objects, we may rest assured that, however little appreciated at the time, our lives have not been lived in vain.

In conclusion, gentlemen, as this is the last time I shall have the pleasure of addressing you from this chair—some of you being aware that I am about to face the difficulties already alluded to in my endeavors to establish a private practice in Westminster—permit me to avail myself of this opportunity to thank you most sincerely for having placed me in the position which I this evening vacate, for the kind assistance and co-operation you have at all times afforded me in my endeavors to advance the interests of this society, and for rendering my term of office such that its rememberance cannot but prove for me a lasting and pleasant retrospect. I may say I look forward with no small degree of confidence to the time when this shall become one of the standard institutions of the West of England. And now, in taking leave of you, allow me to express the hope that each member will do all that in him lies to achieve this result, by which he will not only do honor to his profession and advance the cause of civilization, but will also promote his own individual interests, ever bearing in mind "There is a tide in the affairs of men, which, taken at the flood, leads on to fortune." (Applause.)

THE "GEOMETRY OF POSITION" APPLIED TO SURVEYING.

By JOHN B. McMASTER, C. E.,
Instructor in Geodesy and Topographical Drawing in the John C. Green School of Science, Princeton College.

Written for VAN NOSTRAND'S MAGAZINE.

II.

THE proposition of the Geometry of Position relative to the four points at the intersection of two pairs of concurrent lines, (Fig. 3) is readily applicable to the solution of a second class of problems of very common occurrence in surveying,—the measurement of inaccessible distances.

The cases which, in practice, fall under this head are almost innumerable; as the measurement of the width of a river, the distance across a marsh, the distance of a lighthouse or a beacon from the shore, &c. Yet the solution of any one of them by the Geometry of Position is ample enough to cover them all. To take the first example above cited, let it be required to find the distance of a point C (Fig. 7), on one bank of a river, from a point D, on the opposite bank.

To accomplish this, set the instrument at the point C, sight to D, plunge the telescope, and take any point in the line of sight as A. The line CA will then evidently be a continuation of the line CD, the distance to be measured. Now,

take *any* point *off* the line CA as *a*, such that both C and D are visible from it, set the instrument at this point, sight to D, and take *any* point in the line of sight *a*D as *c*. Then sight to A, previously chosen anywhere on CA, and "stake out" that part of the line *a*A, which seems to cross a line joining *c*C. Sight next to C (the instrument being still at *a*) and "stake out" that portion of the line *a*C which seems to cross a line joining *c* and A. Move now to *c*, sight to *C*, and locate *b*; then sight to A and locate *d*. Set the instrument at *d*, sight to *b*, and find B where the line of sight cuts the line CA. Finally, measuring the distances CB and BA and substituting in equation A,

$$CD = \frac{BC \times AC}{AB - BC},$$

the distance across the river is found. Thus if BC=48.99 feet, then BA=51.01 feet, and

$$CD = \frac{48.99' \times 100'}{2.02'} = 2{,}425.24 \text{ feet.}$$

It is not, however, to be supposed that this proposition of the Geometry of Position does not equally apply to cases in which it is desirable to find the distance and direction of two or more objects from some fixed point. To take an example, suppose at A and C, in Figure 8, are two objects whose distances and directions from some fixed point *b* it is desirable to know.

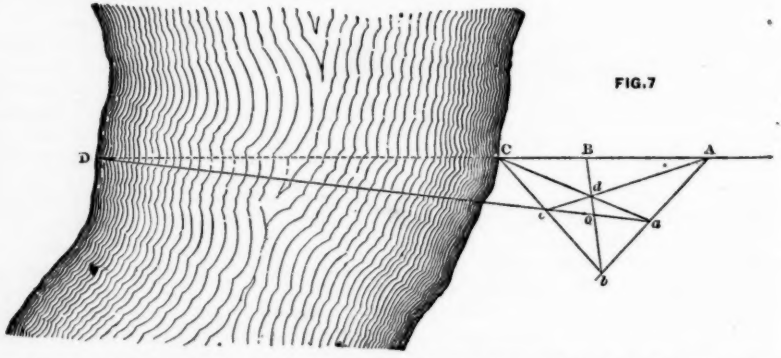


FIG. 7

Referring to Fig. 7, it is evident that if *a*,A,*d*,*o* be considered as the four points of intersection of two pairs of diverging rays from *c* and *b*, and *bc* the line joining the points of divergence (*b* and *c*) of the two pairs of rays, then will the diagonals *ad* and *o*A (Fig. 8) of the figure *a*A*od*, intersect the line *bc* in the two points *c* and *e* respectively. The four points *b*, *e*, *c*, C, will then form an anharmonic range, and from the principles of anharmonic section, already explained, it results that

$$cC = \frac{ce \times cb}{cb - ce}$$

Again, regarding the points *b* and *a* as the points of divergence of the pairs of rays intersecting each other in the four points C*cod*, and the line *ba* as the connector of the points of divergence *b* and *a*, the two diagonals *cd* and C*o*, of the figure C*cod* will intersect the connector *ab* in the two points A and *g* (Fig. 8) respectively. Those two points will form with *a* and *b* an anharmonic range from which may be obtained,

$$aA = \frac{ga \times ab}{bg - ga}.$$

But $bC = bc + cC$ and $bA = ba + aA$, from which the distance required may be readily obtained.

To apply this to the case just taken. The point *b* having been selected, the solution of the question depends on finding the distances *b*C and *b*A and the bearings of these lines. To obtain these, set the instrument at *any point* between *b* and the objects, as *o*, and sighting in *any direction* such that the line of sight *does not cut* the line C A, anywhere between C and A, locate a few points on the line of sight about where it seems to cut a line joining *b* and C. Plunge the telescope, and in a similar way locate a

few points about where the line of sight seems to cut a line joining *b* and A. Sight next to C and locate *g* as nearly as possible; and then sight to A and locate *e* approximately by setting a few stakes where the line of sight A*o* seems to cut *b*C. This done move the instrument to *b*, sight to C and locate *e* and *c* with great exactness. Sight next to A and locate *g* and *a*. Now, having measured *be* and *ec*, as also *bg* and *ga*, and substituting these values in the two equations above given, the values of *c*C and *a*A, are found, which, added to *bc* and *ba* give the required distances *b*C and *b*A. The magnetic bearings are, of course, taken when the instrument is at *b*.

Without stopping to name over the

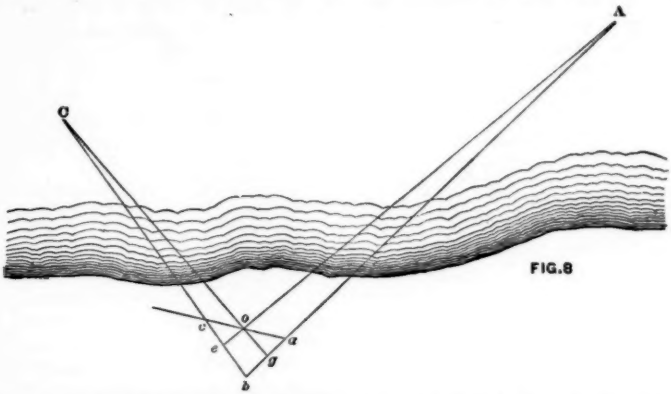


FIG. 8

many instances in which it will be advantageous to apply the two methods of measuring distances illustrated in Figs. 7 and 8, I shall pass to the consideration of a more important matter, the degree of accuracy of the two methods.

Beginning with the first mentioned method (that illustrated in Fig. 7), it is needless to observe that the point A on the line *c*D may be taken at any distance from C. To simplify the measurement, therefore, the distance AC may be taken at one hundred feet and laid off at once by means of a tape. But the distances AB and BC must be measured with great care and to the smallest fraction of a foot. For it is evident from equation A, that as the value of BC approaches that of AB, the value of CD in the expression

$$cD = \frac{Bc \times Ae}{AB - Be}$$

approach infinity, because when AB=B*c* the value of *c*D *is* infinity. It follows therefore that when the distance to be measured is quite a long one, the difference between AB and BC will be very small, indeed but a decimal of a foot. To illustrate with an extreme case, suppose the distance to be measured is 499,950 feet, or something over 94.7 miles; then

$$cD = \frac{49.955' \times 100'}{50.005 - 49.995} = 499950 \text{ feet.}$$

A difference then of .01 of a foot between AB and BC will correspond to a distance CD=94.74 miles. To take a more likely case, suppose AB=50.1′ and BC=49.9′ feet, the distance AC being one hundred feet; then

$$CD = \frac{49.9' \times 100'}{50.1' - 49.9'} = 24950 \text{ feet,}$$

a distance equal to 4.725 miles. In proportion as the distances to be measured are shorter, the differences between AB and BC are larger. Thus, a distance of 2425.24 feet corresponds to a difference between AB and BC of 2.02 feet, while a distance of 1199.37 feet will correspond to a difference between AB and BC of 4.002 feet. A distance of 1 foot on CD will therefore have an exceedingly small difference. If the distance CD, be very great, as five thousand or six thousand feet, the difference between AB and BC corresponding to a foot on CD will be at least some ten thousandths of a foot; if the distance CD be, on the other hand, from one to two thousand feet,

the difference between AB and BC corresponding to a foot on CD will be about one thousandth of a foot. To obtain accurate results it thus becomes quite necessary to be able to measure the distance BC to the ten thousandth of a foot for very large distances, and to the thousandth of a foot for all small or ordinary distances. Thus a distance of 1199.37 feet corresponds to a difference between AB and BC of 4.002 feet, but an increase in the difference to 4.004 of a foot will correspond to a value for CD of 1198.76 feet. Here therefore a distance of .61 of a foot is measured by a difference of .002 of a foot.

This fineness and accuracy of measurement constitutes perhaps, the main objection to the methods discussed above. Yet it is one not impossible to overcome. The distance AC is, for instance, one hundred feet, measured off with all possible accuracy, the temperature and horizontal position of the tape being, of course, fully considered. Now the point B can never fall anywhere on AC except between the middle point of AC and C. For if it falls *exactly* midway between A and C, the point D is at an infinite distance from C or CD is infinitely great. Neither can B fall between A and the middle point of AC, as in that case the point D would fall on the opposite side of A, or, in other words, the point A would be *between* D and B. This never *can* happen in either of the two methods given above, because A and C are chosen at pleasure, and the point D being *sighted to first*, its anharmonic conjugate B must invariably fall between A and C. As a consequence of this fact, it follows that the measurements to the hundredths and thousandths of a foot, need not begin until the fiftieth foot has been passed. Nor, on the other hand, is it necessary that the measurement shall extend for any great distance. If AB be equal to 50.003 and BC 49.997 feet, the value of CD will be over one hundred and fifty-seven miles; if, on the other hand, AB be 55 feet, and BC 45; the difference will be ten feet, and CD will be 450 feet. It will never be necessary, therefore, to go so near the fifty foot point as .01 of a foot, nor so far away as ten feet. The fine measurements, in other words, will be confined to ten feet, and may be obtained in a number of ways that readily suggest themselves. The simplest is by means of a well constructed leveling rod, with a sliding target. If this be used, the center point of the distance AC should first be carefully found, and one end of the rod placed exactly over the point by means of a plum bob, and the rod put horizontally in line with the instrument. It is best to have some simple support for the rod to keep it off the ground, and to enable it to be placed truly horizontal by the aid of a bubble. This done, and the sight *bd*, (Fig. 7), taken to determine the point B, the target may be moved along till it crosses the line of sight, and the distance AB obtained to the thousandth of a foot. If the distance to be measured is very large the vernier must read to ten thousandths of a foot, or the results obtained will be utterly worthless.

The extreme accuracy and fineness of the measurement, thus necessary when long distances are to be measured, render it doubtful, to say the least, whether the methods in question are superior or more practicable than those now in use. The accuracy, however, to be exercised in the measurement of the one hundred feet required between C and A, Fig. 7, is no greater than should be exercised in the measurement of ordinary lines in city surveying, while distances commonly met with in surveying, as the width of a river, or stream, the distance over a marsh, etc., can be obtained without measuring finer than the one thousandth of a foot, which may be done with a common leveling rod. For example, if the distance AB=51.16 feet, and AC=100′ then the distance BC=48.24 feet and Eq. A.

$$CD=\frac{48.24'\times 100'}{3.52'}=1370.45.$$

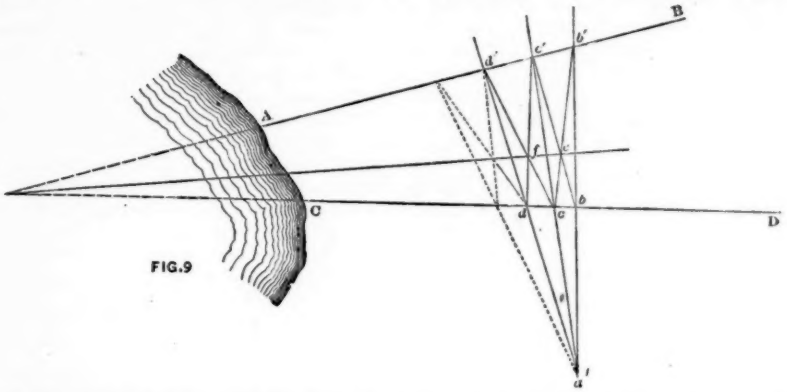
But if AB=51.761 feet then BC=48,239 feet and

$$CD=\frac{48.239'\times 100'}{3.522'}=1369.647$$

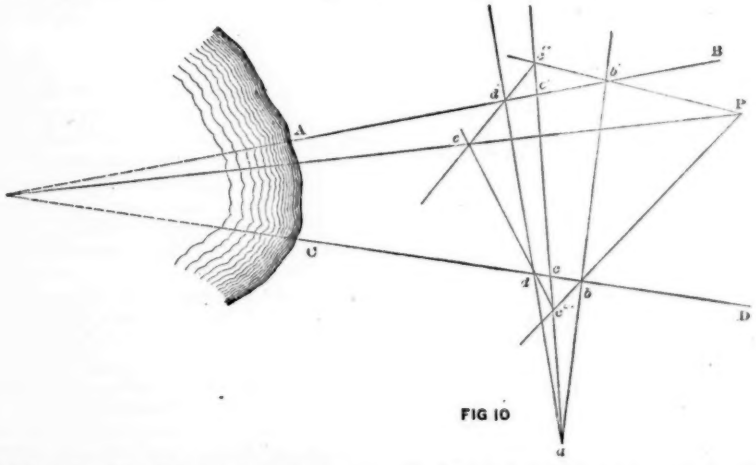
a difference of about eight-tenths of foot. The question then, as to whether this method is better than the old method by logarithms, resolves itself into this; is it better to make one short accurate measurement on the ground, or to make large linear and angular measurements

on the ground, and solve by the rules of trigonometry ?

For the solution of such problems in surveying as do not require the measurement of distances, the Geometry of Position affords methods, the merits of which are unquestionable. Such problems are those requiring the location of lines and very likely to occur in laying out and dividing land, as also in chain surveying, and in town surveying. To take an instance, having two converging lines given as AB and CD Fig. 9, let it be required to pass a line through their



invisible point of intersection. If it be merely required that the line shall pass through the point of intersection, the problem is of the most general form and may be solved as follows : Set the instrument at *any* point not within the lines as *a*, and sighting across them both locate the points *b* and *b'* where the line of sight cuts them. Then turn the telescope so as to cut them at any other place and locate the points *c* and *c'*. Turn the telescope through another angle and locate the points *d* and *d'* as before. Move then to *b* and sighting to *c'* locate the middle part of the diagonal *bc'*. Then move to *c*, sight to *b'* and find *e* exactly, and continue this operation till the diagonals *cd'* and *dc'* are located



and *f* found. The line joining *ef* passes through the point of intersection of AB and CD. Although two points are enough to determine the line *ef* an additional point may be obtained as shown by the dotted lines in the figure. In

using this method it does not make any difference where a is taken without the line, nor is any account taken of the angles the lines ab, ac, ad, etc., make with each other.

If the problem takes a more limited form, and the line must pass through a *given point* and the intersection of AB and BC, the solution may be affected in this wise. Let P (Fig. 10), be the given point. Set the instrument, as in the last case, at any point off the two lines as a and locate, as before, the points b and b'; c and c'; d and d'. Now move to the point P through which the line is to pass, and sighting to b' locate c'' where the line of sight cuts ac. Also sight to b and determine c'''. Move to c'' sight to d' and stake out a portion of the line $c''d'$ beyond d'. Finally, move to c''', sight to d and find e exactly. The line through Pc will pass through the intersection of AB and CD. If the lines AB and CD are very far apart, some time and trouble may be saved by beginning at b, sighting to P and find c'''. Then setting the instrument at c''' sighting to d and locating a part of the line $c'''d$. Repeating this on the other side, beginning with b' the point e is readily found.

When the point P, instead of being *within* the angle made by AB and BC as to the case in Fig. 10, lies *without* the angle as shown in Fig. 11, the line may still be found as in the previous case.

Where it is possible to put the instrument (when used) exactly on the line, a simple method is to begin at b (Fig. 11), sight in any direction and determine b' and then a anywhere on bb' produced. Then sight to P and find c''' approximately. Next take any other point as c sight to a and find c''' exactly, and c'' approximately. Then take d anywhere on the line CD, sight to a and find d', then to c''' and find e as nearly as may be, then find c'' by moving to b' and finally e' by moving to c'' and sighting to d'.

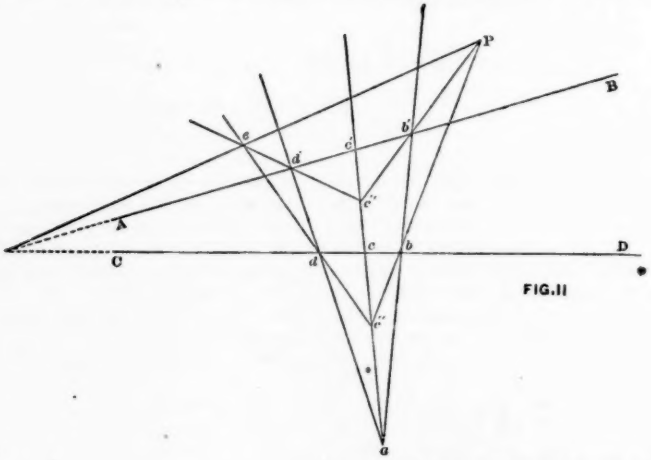


FIG. 11

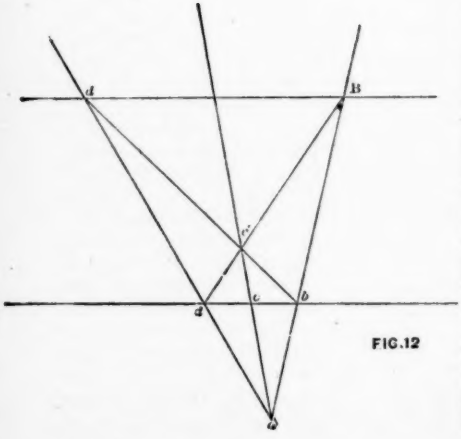


FIG. 12

Of the two, the first method is perhaps of more general application, as it affords simple methods of bisecting, trisecting, &c., the angle formed by the two lines, as will be shown when considering the application of the Geometry of Position to drawing. It likewise affords a solu-

tion to the problem,—of passing a line through a given point parallel to a given line. Let AB figure 12 be the given line and P the point through which it is required to pass a line parallel to AB. Referring to figure 9, it will readily be seen, that, if C′ and *d′* be regarded as the points of divergence of two pairs of rays intersecting at *fdac*, then will *dc* be one diagonal and *af* the other. But if this latter, *af*, be made to cut *d′c′* just midway, then will *cd* be parallel to AB. This gives the solution for the problem in question. Lay off on the given line anywhere, two equal distances *bc* and *cd*. Through the point *b* and the given point P draw a line and in it take *any* point as *a*. From *a* draw lines of indefinite length through *c* and *d*; join *d*P and mark the point *c′* in which it cuts the line *ac*. Through *b* and *c′* draw a line till it cuts *ad* at *d′*. Then is *d′* a point on a line through P parallel to AB.

The solution is undoubtedly of most use in chain surveying; yet it is evident that as affording a means of obtaining the bearing of an inaccessible line, of which two points only are to be seen, it is of value in all branches of surveying. By obtaining a line *parallel* to the inaccessible line, and then finding its bearing the desired result is accomplished.

SIZES OF SAFETY VALVES.

By Prof. R. H. Thurston, of the Stevens Institute of Technology.

From "American Machinist."

The office of a safety valve, as used on a steam boiler, is to discharge steam so rapidly, when the pressure within the boiler reaches a fixed limit, that no important increase of pressure can then occur, however rapidly steam may be made. It has also another office: it should be so constructed and arranged that, should any accident occur, it may be opened by hand and the steam pressure lowered very rapidly, even when the fires in the boiler are burning brightly and generating steam with maximum rapidity. The size of a safety valve is determined by the character of the valve itself, by the pressure at which the steam is to be discharged, by the difference permissible between the pressure at which the valve is to open automatically, and that at which it is intended to be capable of discharging steam as fast as the boiler can make it.

A valve of defective design or badly constructed must necessarily be larger, to do the same work, than one of similar type well designed and constructed. Steam is discharged at any given rate through an orifice of smaller dimensions as the pressure increases: the lower the pressure, on the other hand, the larger must be the valve. A boiler in which steam is carried at twenty pounds by gauge may require a safety valve of thirty inches area, while the same quantity of steam would escape through a rivet hole in a boiler containing steam at pressures such as were attained by Perkins and Albans a generation ago.

Rules by which to calculate the proper area of safety valves for every case arising in his practice, are used by every engineer accustomed to designing steam boilers. These rules vary considerably with differences in the experience or the judgment of their authors. The builder is often inclined to adopt valves of too small size because of the expense of putting on large valves. The engineer, who has once nearly met with a serious accident, to obtain ample security against a repetition of the experience, at once adopts valves of excessive areas; and the designing engineer sometimes bases his rule on improper assumptions, or is ignorant of the true conditions or of the proper method of stating them in the form of a rule. Attention has lately been called to these discrepancies between the rules given by various so-called authorities by a writer in a well-known periodical; but that writer, unfortunately, concludes by commending the rule of Prof. Rankine, which, for general applications, is about the most defective of all. It is correct for certain pressures and under the conditions which existed

in the experiments and observations on which it is based. Containing no reference to the pressure of steam, however, it simply misleads when generally applied. The conclusion is, not that Rankine was careless in framing the rule, but that the engineer, in applying it, must understand under what circumstances it is applicable. The same remarks apply in some degree to rules attributed to the writer. The discrepancies noted in the report of the U. S. Committee on Safety Valves would have been less marked had the rules been properly used.

A rule for general application must always give an area determined by the quantity of steam to be discharged, and the pressure at which it is to be discharged. A perfectly exact rule would involve the determination of other quantities, as the specific volume of the steam, the proportion of water carried by it in suspension, the difference between internal and external pressure. For the purposes of the engineers, these quantities may be neglected, or may be taken into account by a simple modification of the formula used, as will be presently shown.

Rules are very commonly proposed which are based upon the amount of coal burned per hour in the given case. Such rules involve the assumption that each pound of coal evaporates a definite and known quantity of water. Another class of rules make the area of the valve depend upon the dimensions of the boiler, as on the area of heating or of grate surface. These rules involve an assumption that the area of heating or of grate surface is proportional to the quantity of steam made in the boiler in a given time. It is evident that, with a given boiler, the conditions upon which rules of the first class are based are variable, while those of the second are constant. Rules based upon the weight of steam made, or of coal burned, in the boiler must therefore be determined by the *maximum* consumption of coal or production of steam for which the boiler is proportioned. Rules based upon the size of the boiler or area of its grate surface must be so constructed, that the area given by them will be ample for the discharge of more steam than the boiler can make by evaporation from the given amount of heating surface, or by the combustion of all the coal that can be burned upon the grate under the conditions of draught which are to be anticipated. Properly constructed and properly used, it is a matter of perfect indifference which kind of rule is adopted. The two classes of rules will give the same results if both are intelligently framed and applied.

The weight of steam in pounds which will escape through an orifice in the boiler having an area of one square inch is, in ordinary practice, very nearly fifteen times the pressure of the steam measured from the absolute zero of pressure, *i.e.*, above a vacuum. The area of opening, therefore, for any boiler must be, in square inches, the weight of water evaporated per hour as a maximum, divided by fifty times the gauge pressure with fifteen pounds added; *i.e.*

$$A. = \frac{w}{50,\ (p. + 15)},$$

or,
$$a = 0.02[w \div (p + 15)].$$

But a safety valve, as has been stated, should be capable of discharging very much more than the maximum quantity of steam that the boiler can make when doing its best. The valve must be raised, ordinarily, by the action of the steam itself, and the force exerted by the steam pressure upon its disk rapidly diminishes as it rises from its seat. The seat is beveled, too, in such a manner that the effective area for discharge of steam is but a fraction of that due the rise of a valve having an unbeveled seat. It is therefore advisable to give a large excess of area over that above determined. How great this excess shall be is very generally determined by the judgment of the engineer, as formed by observation and experience and checked by direct experiment. Very few engineers, probably, err seriously on the side of excess.

In making up a set of rules for safety valve areas some years ago, the writer adopted the rule: multiply the maximum weight of steam which the boiler is expected to generate per hour by five and divide by ten times the gauge pressure increased by ten; or, divide that weight by twice the latter quantity. Thus,

$$a = \frac{0.5\ w}{p + 10}.$$

From this rule, it is easy to deduce special rules for any other desired application; as to boilers of which the dimensions are given. Thus, the writer had occasion to design safety valves for steam boilers having a ratio of grate to heating surface of about one to twenty-five. These boilers had a "natural draught" and were expected to burn, as a maximum about fifteen pounds of coal per square foot of grate. Such boilers will make, as a maximum, about five pounds of steam per hour per square foot of heating surface. A simple calculation based on these data would give the following set of formulas, in which w=the maximum weight of steam made per hour, h=the area of heating surface, g=that of the grate surface, and c=the maximum amount of coal burned per hour.

$$A=\frac{0.5\,w}{p+10} \quad . \quad . \quad . \quad (1)$$

$$=\frac{2.5\,h}{p+10} \quad . \quad . \quad . \quad (2)$$

$$=\frac{62.5\,g}{p+10} \quad . \quad . \quad . \quad (3)$$

$$=\frac{4\,c}{p+10} \quad . \quad . \quad . \quad (4).$$

For boilers having different proportions, as locomotive boilers with their tremendous forced draughts, or some stationary and marine boilers with their vastly greater proportion of heating to grate surface or to steam made per hour, special rules must be constructed if the designer wishes to base his calculations upon their dimensions. As has been shown above, it is very easy to make such rules, the first of the set having been determined upon. No intelligent engineer will attempt to apply rules like Nos. 2, 3, or 4 to exceptional cases, or, indeed, to use them at all without knowing upon what authority and upon what kind of practice they are based.

Rules in which the steam pressure is not taken into account are only applicable to some one pressure. The same caution is to be observed in using them. It is further evident that rules and formulas are not to be compared except where they are adapted to the same set of conditions, as in the example just given.

Very large boilers require such great area of opening for their safety valves that it is necessary to divide it between two valves; in fact it is always much better to have two valves, even on small boilers. If an accident happens to one, the other is then to be relied upon, usually, to discharge the steam.

The forms of safety valves are almost numberless. A description of some of the best is to be found in the report of the committee on tests of safety valves, appointed from the U. S. Board of Supervising Inspectors of Steam Vessels, in 1875. Among the very best is the ordinary "Lever Safety Valve," of Papin, as modified by the introduction of knife-edged bearing pins by that committee. An excellent little treatise on the safety valve was published in the *R. R. Gazette*, in 1875, by Mr. R. H. Buel and reprinted in Van Nostrand's "Science Series," No. 21. It gives a tolerably complete summary of the principles involved in the design and construction of this most important of the attachments to the steam boiler.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The papers by the Society, not heretofore noticed, are:

Relative Quantities of Material in Bridges of Different Kinds and Various Heights, by Chas. E. Emery.

Description of Survey for Determining the Slope of Water Surface in Erie Canal, by W. H. Searles.

IRON AND STEEL NOTES.

The total amount of iron ore produced in 1876 in the United Kingdom was 16,841,583 tons, and the value £6,825,705. The pig iron produced from the ore was 6,555,997 tons, and the value of the raw material was increased by the expenditure of coal and labor in smelting to £16,062,192. These figures show a considerable increase over the production in 1875. In that year 15,821,060 tons of iron ore, valued at £5,975,410, were raised, and 6,365,462 tons of pig iron, valued at £15,645,774, produced. The increase has been chiefly in the Cleveland district and in Scotland. The production of Scotch pig iron has increased from 807,677 tons in 1874 to 1,103,000 tons in 1876. The Scotch ore requires a relatively large quantity of coal, and the low price of coal has assisted production. The total amount of coal used in the making of pig iron in 1876 was 15,598,381 tons. Much of this was, in fact, used in the form of coke. The Royal Commission on Coal reckoned that three tons of coal are used on

the average to make one ton of pig iron. The figures quoted show that pig iron is now more economically made. It appears from them that the quantity of coal used per ton of pig iron is considerably less on the average than 2½ tons. In addition to the iron ore raised in the United Kingdon, we smelted in 1876 672,235 tons of imported ore, and derived 300,000 tons of burnt or purple ore from imported cupreous pyrites which raised the total quantity smelted to 17,813,818 tons. The current issue of the statistics omits many tables found in the previous publications. Among added lists is one of firms using the Siemens and Siemens-Martin processes for steel. It is printed opposite the list of those using the Bessemer converters, and some names, as that of the London and North-Western Railway Company and the Dowlais Iron Company, appear in both categories.

THE Berlin *Borsen Zeitung* publishes the following table of prices for Bessemer and iron rails respectively at the times stated during the past four years:

		Bessemer rails. Marks per kilog.	Iron rails. Marks per kilog.
1873.	Beginning of the year..	41.67	35 80
	Middle of the year. ...	39.31	33.63
	End of the year.....	35.42	27.12
1874.	Beginning of the year..	35.60	28.76
	Middle of the year.....	29.85	19.37
	End of the year.....	26.31	18.32
1875	Beginning of the year..	26.14	18.92
	Middle of the year.....	21.30	17.41
	End of the year.....	19.53	17.50
1876.	Beginning of the year..	18.87	15.31
	Middle of the year.....	16.93	15.00
	End of the year.....	17.75	16.93

RAILWAY NOTES.

THE working of the Mediterranean or Western group of lines which has just been formed by the Italian Government is to be entrusted to the Italian *Credit Mobilier* and the General Bank of Rome.

A COMPANY is, says *Le Propagateur*, being formed in Paris with a capital of 200,000 francs, which will be employed in defraying the cost of designing and constructing a steam tramway motor, and in experiments, in order to discover the most economic method of working street tramways by steam power.

BERLIN is at a loss as to the disposal of its Metropolitan Railway. Soon after the Franco-Prussia war Berlin found it necessary to have a railway. It has now 1,000,000 inhabitants, who live in flats four stories high without gardens, parks, and with but a few squares, so that it is, in comparison to London, of but small extent, and a railway is not actually needed even now, much less five years ago. However Berlin had made up its mind to have a railway of its own, and a capital of 78,000,000 marks was soon subscribed. The State took 21,000,000 marks, the German Building Co., 12,000,000 marks, and three railway companies took the rest.

A RECENT number of the *Annales des Ponts et Chausees* gives the following information, furnished by the officers of the railway from Hanover and Cologne to Minden. The proportion of pine ties, injected with zinc, renewed after twenty one years, was 21 per cent; beech ties, injected with creosote, renewed after twenty-two years, 46 per cent; oak ties, not injected after seventeen years, 49 per cent; oak ties injected with chloride of zinc, after seventeen years, 20.7 per cent. The ties which were not renewed appeared perfectly sound. Since 1870, the Emperor-Ferdinand Northern Railway has used only oak ties, injected with either creosote or with chloride of lime.

MESSRS. FOX, WALKER, & Co., of Bristol, have been entrusted by Mr. Vignoles, the engineer for the Rouen tramways, with the design and execution of six locomotives for working the traffic, and the first of these engines has, during the last week, been subjected to a series of severe trials on what is probably the most difficult tramway system in the world, that of the city of Bristol. Besides various steep gradients for long distances, and the sharp curves on turning from one narrow street to another at right angles, there is in Maudlin street an incline of 1 in 12 for a distance of 90 yards, including a curve of 45 feet radius at the summit. Yet this combination of difficulties was, on Saturday last surmounted by the locomotive, in the presence of the engineer and directors of the Bristol Tramways Company. The engine is 10 feet 6 inches long over all, the wheel-base being 4 feet 6 inches, and the gauge rather less than 4 feet 8½ inches. The ends are rounded, so as to clear in running round curves, and the connections are made by a combined coupling and central buffer. A cab encloses the engine, giving it the appearance of an ordinary tram-car, while wrought iron curtains, reaching down to within a few inches of the rails, completely conceal the wheels and side rods. Two flap doors at the side are, however, provided for oiling. The grate area is 4.6 square feet, and the total heating surface 96 square feet, providing ample steam for the pair of outside cylinders, 8 inches in diameter by 9 inch stroke the ports of which are rather large, so as to take steam easily, and get as much effective pressure on the piston as possible. The wheels are of cast steel, 2 feet in diameter, and all four coupled. The exhaust steam is caused to expand as much as possible by being passed through a cage made of wire wound spirally round an open cylindrical frame, and also through an annular orifice which causes it to completely fill the chimney instead of allowing it to issue in a central jet, by which means the usual noise of the blast is prevented. Smoke is avoided by the use of South Wales smokeless coal. The steam blowing off from the safety-valves is received in a casing, and led by a pipe into the ashpan, so as to damp down the fire, and thus acts as an automatic pressure regulator. The steam and water from the cylinder cocks, gauge cocks, and water gauge is led away into the ashpan, which is made double, so as to retain the ashes for the whole of the run; and the coal is charged on the bars in brown paper parcels for convenience, and also for the avoidance of dirt and dust. The steam

stop-valve is only used on starting and at the end of a journey, as the reversing lever, which can be shifted under steam, suffices for starting, stopping, and reversing on the run. By this means alone the engine can be stopped in its own length while running at the rate of ten miles an hour: but for descending sharp gradients, powerful break straps are applied by treadles to two cast iron pulleys keyed on the leading axle. The motion of the locomotive is remarkably easy, and no less so is the readiness with which she answers the regulator.

ENGINEERING STRUCTURES.

ST. GOTHARD TUNNEL.—At the northern opening granitic beds have been encountered, and at the southern end abundant springs of water. These difficulties have been completely surmounted. The Italian journals anticipate the completion of the work by the spring of 1880, provided the necessary funds are raised. —*Les Mondes.*

SHIP CANAL ON THE SEINE.—Preliminary formalities are being carried through at Havre for the construction of a maritime canal from that port, touching at Harfleur, and joining the Seine at Tancarville, a point on the River about sixty miles below Rouen. By means of this canal the dangers of the navigation of the Lower Seine from fogs, the shifting sands, and the violence of the tidal wave, will be avoided. The canal will consist of a single section of about seventeen miles in length, the western outlet of which will be in the Eure Dock, at Havre. According to the plans adapted, the canal would have a minimum breadth of twenty-five meters (over eighty feet,) with a towing path six meters wide on each bank. Plans have been adopted for increasing the depth of the channel of the Seine between Paris and Rouen to three meters twenty (10½ feet); a minimum of three meters fifty has, consequently, been fixed for the canal; and as between Havre and Harfleur it is to be accessible for brigs, schooners, and steam colliers, the depth in that portion will be increased to 4½ meters. The cost of the work is estimated at 21,000,000 francs, including all accessory works, the planting of the banks with trees, the construction of a branch, 500 meters long, to connect the port of Harfleur with the canal, and a basin of 500 meters by 60 meters at Havre.—*Coal Journal.*

DARIEN INTER-OCEANIC CANAL.—At a recent meeting of the Academy of Sciences, in Paris, M. de Lesseps, the constructor of the Suez Canal, and President of a commission to consider the best means of accomplishing inter-oceanic communication across Central America, reported that after considerable preliminary examinations the Isthmus of Darien was the best route. It would have the immense advantage of not requiring any locks, as the Pacific and Atlantic are at a level in that region. The canal would have a total length of sixty-five kilometers (five-eights of a mile each) from the point where the River Tuyra, which falls into the Pacific ceases to be navigable to the Atlantic. The ground is very favorable, the vegetable mould varying in depth from two to seven meters, and below that soil is found, throughout nearly the whole length, tenacious clays, which are invaluable in a country subject to tropical rains, as they will not be washed away to silt up the canal. The whole district is covered with a virgin forest, containing trees admirably adapted for hydraulic purposes, as they are extremely hard, and are not attacked with worms. Limestone is found in ample quantities for the necessities of the undertaking. But—and here comes the difficulty—a tunnel will have to be made fourteen kilometers in length, and as a passage for the largest vessels will have to be provided, it must be thirty-six meters (118 feet) in height. Its construction is estimated to cost 300,000,000 francs, and the other works an equal sum.—*Railway Review.*

AMERICAN BRIDGES FOR CANADA.—The Phœnixville Bridge Company are building a number of iron bridges in the line of the Montreal, Ottawa, and Occidental Railway, Canada, under contract with the Canadian Government. Annexed are some details of these bridges. On the Eastern division there is one at St. Ann's, 40 miles west of Quebec, having seven spans of 160 feet each; one at Batiscan, with four fixed spans of 160 feet each, and a draw of the same length; and one at the Three Rivers, half way from Quebec to Montreal, of five spans, each 219 feet in length; and 50 feet from the water. On the Western division, at Buck River, 7 miles west of Montreal, a 50 foot span has been finished over a small stream, and near by two spans of 155 feet each, and one of 200 feet will soon be in place. At St. Rose one of five spans, of 155 feet each, is being built; at the Scholastic River, a 50 foot span; at La Chute three spans of 104 feet each; at Calumenta 50 feet span; at the River Rouge three deck spans of 150 feet each; at Anchcene Creek and Salmon Creek one deck span each of 50 feet; at Salmon River a 100 foot span; at North Nation River three spans of 100 feet, 150 and 200 feet; at Little Blanche River a 50 foot span, at River Blanche one span of 100 feet; across Au Leivereres River, at Buckingham, one span of 100 feet and three of 150 feet each; at Little Upper Blanche a deck bridge of 50 feet; at Upper Blanche, one span of 100 feet and at Gatineau four spans of 204 feet each. All these bridges are of wrought iron, with iron floor beams and track stringers, wooden ties 8 inches by 8 inches, and 8 inches apart, and the necessary guard rails and iron. They are shipped to Canada in barges by canal, and have to pay a duty of 17½ per cent. on their cost.

ORDNANCE AND NAVAL.

THE INFLEXIBLE.—The report of the Committee composed of Admiral Sir James Hope, Dr. Woolley, Mr. G. W. Rendel, and Mr Froude, appointed by the Admiralty to inquire into the stability of the Inflexible, has just been issued, and will be studied with the closest attention by all who are interested in our Royal Navy, and especially by naval archi-

tects, and by the officers and men of the fleet whose lives are concerned in the safety of the ships they will have to fight and manœuvre in the presence of the enemy. No subject connected with Admiralty affairs has excited so much attention since the loss of the Captain, as this question of the safety of the Inflexible and the other vessels of her type, which has been under investigation for many months.

The report of the Committee now to hand, although it appears at first sight to acquit the Admiralty Constructors of all blunders regarding her stability, can only add to the apprehensions already felt concerning the safety of the vessel in action, and lead to further inquiry, for it corroborates all the statements of fact put forward by the *Times* and by Mr. Reed in condemnation of her.

The report in substance is a verdict for the Constructors of the Navy of "not guilty but don't do it again." When analyzed it will be seen that the recommendations of the Committee at the end of the report, regarding the type of vessel, are utterly inconsistent with the opinions they express as tothe merits of the particular ship. They hesitate to condemn the Inflexiblewhich is already built, and they equally shrink from any responsibilityfor her repetition. They consider that a just balance has been maintained in the design, so that out of a given set of conditions a good result has been obtained; yet they dwell upon "the great advantages which a further increase of beam would give to vessels of the Inflexible type," and they "bring under the very serious consideration of their lordships the necessity, before proceeding with the construction of more vessels of the type of the Inflexible, of thoroughly investigating whether by more beam their safety may not be largely increased without impairing their speed and efficiency."

As we have intimated above, this report when analyzed will be found to be as unsatisfactory, inconsistent, and disquieting a document as has ever been put forward on such a grave question.

We purpose examining it in detail, having regard to the real points at issue. In the first place does the Inflexible fulfill the conditions she was intended to fulfill? Does she depend for her stability and safety on her unarmored ends? Sufficient evidence now exists to settle these points once for all. The other question as to how far the unprotected ends are susceptible of damage under shell fire, has from the first been regarded as a matter of mere opinion until it is settled by artillery experiments.

Let us now see from the report of the Committee how the fact stands with reference to the dependence of the ship for stability on her unarmored ends. It will be seen in the answer to the second question, "As to whether there would be any risk of the ship capsizing if she were placed under the conditions mentioned in the previous paragraph [viz., the complete penetration and water-logging of the unprotected ends of the ship, and the blowing out of the whole of the stores and cork by the action of shell fire], supposing that the water ballast for which provision has been made, were admitted into the double bottom of the armored citadel, or whether she would retain a sufficient amount of stability to enable such temporary repairs to be executed as would enable her to reach a port."

This is simply the condition, be it borne in mind, without the cork and canvas which the security of the ship was not to be dependent upon. The Committee say (and mark the guarded way in which it is put): "We find that under the extreme conditions assumed the ship, even without water ballast, would yet have stability, and would, therefore float upright in still water, and we are of opinion that the stability that she would have in that condition though small, is in consequence of the remarkable effects of free internal water in extinguishing rolling, sufficient to enable her to encounter with safety waves of considerable magnitude. The ship under these circumstances, however, would require to be handled with great caution. The admission of water as ballast increases the amount of stability, and is thus of advantage as against steady inclining forces, but on account of the deeper immersion it involves, it does not materially increase the range of the stability. When the immersion is such as largely to increase the depth of the water on the middle deck, it appears that the extinguishing effect of such water becomes less vigorous, so that in a seaway the ship would in the extreme condition be safer with a moderate than with a very large amount of water admitted as ballast."

"It must be clearly understood, however, that we should consider the ship in a very critical state if reduced to this condition in the presence of a still powerful enemy. Her speed and power of turning would be so limited as to prevent her being maneuvered with sufficient rapidity to insure her against being effectively rammed, or so as to avoid a well-directed torpedo, while the small residuum of stability she would possess would not avail to render such an attack other than fatal. Her guns would also have to be worked with great caution, and under restrictions imposed by the high angle to which their combined movements would in broadside firing heel the ship. We have already expressed our opinion that it is in a high degree improbable that the ship would be reduced to this condition, even in a protracted engagement. We think that the destruction implied by the extreme condition assumed, would be such that nothing effective could be done in the way of repair at sea under any circumstances."

Here everything is vague, general, and at first sight strikes the reader as being well weighed and cautious.

A significant light is thrown, however, upon the condition of the ship, as here referred to, in a paragraph on page 16, which we must quote, for it does not appear in the summary, and is likely to escape attention. It says: "The Inflexible riddled and gutted, and without water ballast, going at the 7.24 knots, and turning in the circle of 1210 feet, in diameter, would require a righting lever or G Z of .13 ft., and as the value of G Z at her maximum stability in this condition is only .12 ft., she would on this supposition overset. It is, how-

ever, not to be expected that the ship under this condition could be driven at this speed, which with the Thunderer corresponded with 11.14 knots on the straight course."

They do not say, as we are quite sure our readers will say, that the ship having such a small fraction of the stability that proved too little for the Captain, and being in such a state that she would capsize by the action of her helm, would in all human probability go to the bottom in a sea-way, and is to all intents and purposes in the condition the *Times* and Mr. Reed said she would be in. The Committee, however, would only consider the ship in a very critical state if reduced to this condition *in the presence of a still powerful enemy!* as if any foe other than the ocean could be necessary to render such a case critical. Again, their apparent admissions that she would have to be handled with caution, and that she could not be maneuvred with sufficient rapidity to insure her against being effectively rammed, or so as to avoid a well-directed torpedo, are facts it is true, but they are facts put in such a way as to hide the real truth, and to avoid saying, what must force itself on the mind of any one, that the ship in that condition is hopelessly crippled and unsafe. Yet this is the condition in which oftener than in any other the safety was promised and guaranteed by the Constructors. How it is possible in view of the above figures for the Committee to say she has sufficient stability to enable her to encounter with safety waves of considerable magnitude we cannot conceive. Of this we may be quite sure, no one would dare to put it to the test in this country, by risking valuable lives on the faith of such an assertion. Captain Boys bases his opinion that the cork cannot be blown out, on the assumption that the vessel in the intact condition will not roll. The Committee are equally certain the Inflexible would not roll in her crippled condition. Doubtless when a ship is water-logged she is not so lively as ordinary vessels, but water-logged ships as a rule end by turning over and going to the bottom. It is moreover in the recollection of every one that it was claimed to be one of the chief merits of the Captain that she would not roll, and the constant repetition of the assertion did perhaps more than any other single cause to bind the present Constructors of the Navy to the dangers of that unfortunate ship. For this reason among others, we view with the utmost alarm the propagation of such ideas as that a vessel in a crippled condition, unable to turn at half speed without capsizing, and with a maximum righting lever of less than 1½ in., has stability sufficient to enable her to encounter with safety waves of considerable magnitude.

The Committee's recommendation to stop the construction of the other ships of the Inflexible type atones in some measure for their over-indulgence to her, and their discovery of the dangers existing in regard to her longitudinal stability will go far to rescue their inquiry from the charge of failure. Their statement that, "At present the inclining moment due to the running out of the guns is over 1,600 foot-tons, and becomes a serious element of danger as the ship approaches the riddled and gutted condition," and their strong recommendation that the travel of the guns on their slides would be reduced to mitigate this evil as much as possible, show how little faith they have in their own recorded opinion that the ship would never be brought to a condition needing such precautions.—*Engineering.*

BOOK NOTICES.

THE PICTURE AMATEUR'S HAND-BOOK. By PHILIPPE DARYL, B.A. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price $2.00.

This is a short treatise on the various schools of Painting, with some explanations of processes of painting, relining, restoring, &c.; all of which is briefly but well presented. This is followed by a dictionary of artists, giving in case of the most renowned a short biographical sketch.

It is a very convenient hand-book for that large class of visitors to picture collections, who would gladly know more about the pictures than they can glean from catalogues, or from any other source to which access is by any means convenient.

ALBUM TO THE COURSE OF LECTURES ON METALLURGY, AT THE CENTRAL SCHOOL OF ARTS AND MANUFACTURES AT PARIS. By S. JORDAN, C.E., M.I. Paris: J. Baudry.

The author explains in his preface that his needs, both as professor and engineer, prompted him to prepare a methodical and complete set of drawings which should exhibit the improved machinery now used in iron and steel manufacture. The object aimed in publishing the work, was to furnish engineers and managers of iron works with such examples of apparatus as should guide them in designing a new plant, or improving that already in use.

The work is divided into four parts as follows; viz; Part I, Fuel; Part II, Production of Pig Iron from the ore; Part III, Manufacture of Malleable Iron; Part IV, Manufacture of Steel.

The plates, one hundred and forty in number, form a large atlas, and are admirably designed for service as working drawings.

THE SILVERSMITH'S HANDBOOK. By GEORGE E. GEE. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price $3 50.

This is a thoroughly technical work designed for the Artisan only.

It aims at complete instruction in the different modes of alloying, and melting silver; its solders; preparation of imitation alloys; methods of working and prevention of waste.

The contents of the several chapters are as follows.

Introductory—Chap. 1, Silver; 2, Sources of Silver; 3, Assay of Silver ores; 4, Cupellation; 5, Alloys of Silver; 6, Various qualities of Silver; 7, Silver Solders; 8, Melting Silver; 9, Working Silver; 10, Enriching the surface of Silver; 11, Imitation alloys; 12, Economical processes; 13, Licences and duties (English); 14 and 15, Miscellaneous.

It is a well printed 12 mo. volume with 40 wood cuts.

A Manual of Heating and Ventilation in their Practical Application. By F. Schumann, C. E. New York: D. Van Nostrand. Price $1.50.

Now that the public mind is ready to assent to the urgent demand for sanitary reform, a practical guide to such improvement is clearly a widespread want. The need of pure air and proper temperature in our dwellings has been sufficiently urged, that is to that degree that all intelligent people assent to the main principles. The knowledge of how to accomplish the desired end in the most practicable way has not been so readily forthcoming.

This little Manual is designed to afford to Engineers and Architects the necessary formulas and tables for dimensions of heating pipes and ventilating flues of all kinds.

Under the heading Ventilation, the author gives the established formulas for amount of air supply with dimensions for supply and exit pipes, velocities of air currents, friction in the flues, &c.

Heating in like manner includes formulas and rules for obtaining the proper amount for any given space; for calculation of loss by radiation, by contact with air, and through the various bounding walls of the apartments. Also rules governing the use of Steam Pipes and Hot-Water Pipes.

Furnaces, Boilers and Chimneys receive a fair share of attention.

The Manual is useful in the hands of practical men only, and those who are familiar with the theoretical principles. It is well printed and enclosed in a substantial binding, suitable for a pocket reference book.

Matter and Motion. By J. Clerk Maxwell, LL.D., F.R.S. London: Society for Promoting Christian Knowledge. New York: D. Van Nostrand. Price 50 cts.

This, although one of the Manuals of Elementary Science, must not be regarded as presenting only the rudiments for beginners. A discussion of the fundamental ideas of physical forces by one of the foremost scientists, demands the attention of every teacher and student of physics

The author's preface reads thus:

"Physical Science, which up to the end of the eighteenth century had been fully occupied in forming a conception of natural phenomena as the result of forces acting between one body and another, has now fairly entered on the next stage of progress—that in which the energy of a material system is conceived as determined by the configuration and motion of that system, and in which the ideas of configuration, motion, and force are generalized to the utmost extent warranted by their physical definitions.

To become acquainted with these fundamental ideas, to examine them under all their aspects, and habitually to guide the current of thought along the channels of strict dynamical reasoning, must be the foundation of the training of the student of Physical Science.

The following statement of the fundamental doctrines of Matter and Motion is therefore to be regarded as an introduction to the study of Physical Science in general."

The subjects in order of treatment are: Motion Force; Properties of the Center of Mass of a Material System; Work and Energy; Recapitulation; The Pendulum and Gravity; Universal Gravitation.

The Draining of Lake Fucino. By Alexander Brisse & Leon de Rotrou, translated by V. De Tivoli, Jr. Rome: Propaganda-Press. For sale by D. Van Nostrand. Price $25.00.

This bulky volume with its Atlas of elegant plates, presents a complete history of this extensive engineering operation. The work was carried out at the expense of Prince Alexander Torlonia. It was begun twenty-three years ago, and is just now approaching completion.

Many circumstances concur in imparting to this enterprise a special interest which similar works elsewhere can not claim.

Julius Cæsar first proposed to drain the lake. Claudius was the first to attempt it; his failure was repeated by Trajan, by Hadrian, and in later times by Frederic II, by Alphonso I of Aragon and by several sovereigns of Naples. It was given up as an impossibility till Prince Torlonia began in 1854 the operations which have just been crowned with success.

This famous lake which was somewhat elliptical in form, was 12.4 miles long and 6.8 miles in width, having an area of 173,000 acres. Having no outlet it was subject to great variations in level, and so was a constant source of anxiety to the inhabitants along its shores.

The tunnel through which the drainage was effected was 6887.5 yards in length, and was completed in 1869. The history of the present enterprise is the more interesting by reason of the fact that, incorporated with it, is the account of the work of the older engineers, much of which was revealed for the first time by the later excavations.

The entire work is given in both French and English, the two narratives appearing on opposite pages throughout. The plates are colored and form a large Atlas.

Graphical Statics. By A. Jay Du Bois, C.E., Ph. D. Second Edition, Revised and Corrected. New York: John Wiley & Son, Publishers, 1877.

This work is intended to introduce to the American public the new science of the graphical computation of statical problems as taught in Germany; of which it claims to set forth the theory and practice in a systematic manner.

The book, so far as we have observed, has been well received in the public prints; we are therefore led to examine it somewhat carefully.

It must be confessed that the courtesy which has been extended to the work, and for which the author thanks the public, has been due largely to the ignorance of graphical methods which prevails in this country. Had the work been published in Germany, in the German

language, it would have met a merited and a universal condemnation.

The book consists principally of literal translations selected from the principal German writers upon this subject, with extracts from certain English and American sources.

It was to be expected that in a treatise like this some attempt, at least, should be made to digest the material employed; and that care should be exercised that investigations such as occur in the subject of continuous girders for instance, should not be given more than once under forms which differ in notation only.

This, and the exceedingly curious and awkward arrangement of chapters, supplements and appendices, which is very striking, is the result of making a patchwork book with the scissors instead of the pen. From the same cause it happens that those bending moments which are considered positive in one part of the book are taken as negative elsewhere.

Again, at the middle of page 68 a certain expression is stated to be the equation of an ellipse. Bauschinger, from whom the author is translating at this point, adds, that the equation is expressed in terms of "line co-ordinates." Now we venture to assert that there is not an under-graduate student in our schools, such as this book was intended for, who is familiar with equations in line co-ordinates. It may even be supposed that the author, as he is yet quite a young man, is not in the habit of working with them. It may reasonably be supposed that he omitted the words from his translation because he did not understand them. It can hardly be that he supposed his readers more intelligent mathematicians than those for whom Bauschinger wrote his treatise. Now a curious consequence follows from this intentional omission, to wit, that the author does not recognize the ordinary equation of an ellipse when he sees it; for this equation he asserts to be that of an ellipse, meaning it, of course, in ordinary Cartesian co-ordinates, but it is not the equation of an ellipse when so interpreted. This degree of ignorance is unpardonable in a mathematical treatise.

The use of "center of action," sometimes for "center of gravity" and sometimes for "center of percussion," as well as the contined use of "moment of inertia" for what all English writers use another term, "products of inertia," or "moments of deviation," or some term which shall distinguish it from the proper moment of inertia, are suggestive of a defective training in elementary mechanics. There are several particulars in which the author has offended against the canons of good taste,—to use no stronger term.

One feature, which we must consider objectionable on the score of good taste, is this wholesale use of matter transferred bodily to the pages of the book without quotation marks. The author states continually that he is indebted for the substance of such and such an article or chapter to this or that writer; no reader, however, would be led to infer from such acknowledgements that the total indebtedness is really what it is. The author quotes so naturally that it seems to be a nearly unconscious process: compare the last half of the first page of his *preface*, (which one would certainly expect to find original with the author) with the last paragraph but one on page XXXVI, translated from Weyrauch.

Another matter in which the author offends good taste is in the praise he bestows upon his own work. He is more self-conscious than any mathematical writer which we have had the fortune to read for many a day. We forgive such things in case of a great genius.

It is true that the author lays claim to certain applications of the frame-diagram method as being original with himself, but the cultivators of that method all agree that they can determine the pressures in any frame or part of a frame, such as he discusses, when the external forces are known, and they will hardly admit any claim except that the cases he discusses have not been directly copied from any one. Such a small claim need not be jealously guarded, or any parade made of it.

Another offence against good taste is in the English used. The style is inelegant, the grammar dubious, the punctuation abominable. The frequent mis-spelling of the word asymptotes by introducing a superfluous *s* is particularly trying. In certain passages no sense can be extracted from the sentences by the ordinary student. In short, the language lacks the clearness and exactness requisite for the treatment of such a subject, and is that in vogue with the newspaper correspondent of the period.

A last objection urged in behalf of good taste finds its text on the last pages of the book, where the author has seized the opportunity of attacking the opinions of a member of the American Society of Civil Engineers, which opinions the gentleman had advanced in a paper printed in the Transactions of that Society. Be the opinions correct or incorrect the author had no right to put the gentleman upon a perpetual pillory by ostentatiously calling him by name again and again with the intention of convicting him of error and discrediting him in the eyes of the readers of this book. It is not within the province of a systematic mathematical treatise, even though it include practical applications to inaugurate on its pages a personal controversy.

That part of the book which treats of flexible arches, stone arches, and the stiffening truss of suspension bridges is already superseded by the new and superior methods given during this year in a series of articles in VAN NOSTRAND'S ENGINEERING MAGAZINE by Professor Eddy. But aside from those articles the stone arch in particular is badly treated. The author, however, does not seem to have copied his treatment verbatim from any previous author. The method of trial for finding the curve of pressures is especially objectionable, and the principle stated at the bottom of page 317 from which its true position is to be found is completely false. The notation used in referring to the numerous figures is excessively irksome and wanting in the first elements of fitness, especially in Chapter II where the author is dealing with fundamental principles, which should be encumbered with as few difficulties as possible.

Another curious circumstance reveals itself in connection with the notation employed. It is evident that the author was unacquainted with Bow's book, to which he refers, until his own was about half completed, at which point he adopts Bow's notation. This is probably not the only instance in which the plan of the work was changed as the work progressed. Internal evidence points to large fractions of the work which were interjected as an after thought.

In what particular does the second edition differ from the first? For one thing, the author reluctantly modifies, in his second preface, the over enthusiastic assertions still retained in the body of the book respecting the economy of continuous girders for successive spans. We notice also that four pages of new matter are introduced at one point containing an illustrative example, and that a slight change is made at one other place. We have discovered no other alteration.

The author states that the second edition "has undergone a careful revision and correction, and no pains have been spared to render it free from typographical errors." A careful reading of the first edition has revealed the following errata in the coarse print on the first 160 pages in formulæ and letters referring to diagrams.

Page	64	line	28, for	$m'' L$	put $mn'' L$.
"	66	"	7, "	ox	" Ox.
"	66	"	8, "	$0x$	" Ox.
"	67	"	21, "	xe & ye	" xe^2 & ye^2.
"	89	"	33, "	P_1MB	" AMB.
"	127	"	4,	insert	H.
"	139	"	28, "	NV'	" MV'.
"	144	"	22, "	W_1W	" W_0W.
"	150	"	8, "	BCT	" BGT.
"	155	"	15, "	K	" P.
"	155	"	9, "	80	" 95.
"	155	"	32, "	75	" 95.

These are all but one of the errata of this important class found on these pages. Not one, of them was corrected in this second edition. nor have we found any case of correction of a typographical error in the second edition Numerous other errata of various kinds were found, not one of which has been corrected. For example there are several bad ones in the figures of which we may note that the kernel in Fig. 37, plate 11, is wrong side up. The Figs. are many of them taken bodily from German books, and some are copied incorrectly.

There are other defects in the work of lesser magnitude to which we shall not now call attention.

In the final paragraph of the author's first preface, which is quoted in the original German from Culmann, and also in the only passage in which the author's introduction differs from Weyrauch, he, as elsewhere, ranges his work beside that of Culmann and Bauchinger, the creators of modern Graphical Statics. The stripling on taking up his arms assumes the air of the aged warrior of a hundred battles. This is sheer impudence, not only is this author not entitled to assume such a tone, but he has no right to speak as an authority upon the subject at all. He has made no investigations, he has earned no place in science except such as this book may give him, which is not an high one, for he has failed in it to assimilate and put in homogeneous form even the work of others.

MISCELLANEOUS.

THE longevity of various trees has been stated to be, in round numbers, as follows: Deciduous cypress, 6,000 years; baobab tree of Senegal, 5,000; dragons' blood tree, 4,000; yew, 3,000; cedar of Lebanon, 3,000; olive, 2,500; oak, 1,600; orange, 1,500; Oriental plane, 1,200; Cabbage palm, 700; lime, 600; ivy, 600; ash, 400; cocoa nut palm, 300; pear, 300; apple, 200 years. The Brazil wine palm arrives at the age of 150 years; the Scotch fir gets its growth in about 100 years, and the balm of Gilead in about 50 years.—*Northwestern Lumberman.*

AN English writer, speaking of the different varieties of wood found in Australia, says: The blue gum of Van Dieman's Land is found abundantly in some of the forest districts, principally of the south, and is well known for its colossal size, so that it is superfluous to quote the statements made of its vast dimensions. Of the circumference of the stem instances are on record by which this tree ranks only second to the famous boabab from the Senegal. The experiments in Van Dieman's Land have shown that its strength and elasticity exceed generally those of all woods hitherto tested. It is equal in durability to oak and superior to it in size, and therefore highly esteemed for shipbuilding. Other *eucalypti* likewise claim attention on account of the beauty and durability their wood; in consequence of which qualities, one of them, from the south-eastern frontiers, received there the name of the mahogany tree. The wood of the *callistemon salignus*, although the tree is seldom of large dimensions, stands here perhaps unrivalled for hardness. The fragrant myall wood, so well adapted for delicate ornamental work, is obtained from *acacia malophylla* and some allied species of the Mallee desert. The well known blackwood, in some localities called lightwood, attains in the fern tree gullies an enormous size, and yields a splendid material for furniture, and, capable of a high polish, being also recommended for the finishing work of vessels. The myrtle tree of Sealer's cove and the Snowy river is also remarkable for its straight growth and its excellent wood. The Australian ever-green beech forms a noble tree, sometimes more than 100 feet high, of which the wood takes a beautiful polish. Omitting such kinds as are chiefly known, we may mention as useful for ornamental work the sassafras wood, the lomatia wood, the tolona tree, the musk wood, the iron wood, the zleria wood, the heath tree, and the Australian mulberry tree.